Nighttime Videographic Projection Mapping to Generate Photo-Realistic Simulation Environments

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Abstract

This paper presents a methodology for generating photo realistic computer simulation environments of nighttime driving scenarios by combining nighttime photography and videography with video tracking [1] and projection mapping [2] technologies. Nighttime driving environments contain complex lighting conditions such as forward and signal lighting systems of vehicles, street lighting, and retro reflective markers and signage. The high dynamic range of nighttime lighting conditions make modeling of these systems difficult to render realistically through computer generated techniques alone. Photography and video, especially when using high dynamic range imaging, can produce realistic representations of the lighting environments. But because the video is only two dimensional, and lacks the flexibility of a three dimensional computer generated environment, the scenarios that can be represented are limited to the specific scenario recorded with video. However, by combining the realistic imagery from video and photographs with the flexibility of a computer generated environment, it is possible to vary any number of factors such as the speed of vehicles and the driver lane position, and to vary the types of vehicles and lighting conditions involved in the scenario. The combination of projection mapping, video tracking, and nighttime video and photography methodologies allow this flexibility. In addition to presenting the methodology and the resulting computer simulation environment, the final simulation is compared to actual video recordings of the same driving scenario to evaluate how similar they are in value, tone, color and visibility.

Introduction

Pursuing realism when attempting to simulate or recreate driving environments has continued to advance in industries that range from automotive safety and testing to video gaming and entertainment. The realistic simulation environment helps the user visualize the driving environment in a manner that more closely resembles the actual environment one experiences in the real world while maintaining the safety of a simulated scenario. Another advantage of the simulated environment is that, because it is completely computer generated, variables such as the roadway conditions, vehicle speeds and positions, and lighting conditions can all be changed, and a variety of factors that potentially contribute to accident causation can be visually represented for use in analysis, studies or demonstrations. Some environments are more difficult to model than others, particularly low light level and nighttime environments where reflected light, and artificial lighting sources create complex lighting situations [3]. However, advances in digital photography and videography have made imaging these environments easier and more realistic. This paper discusses processes for creating simulated driving environments by utilizing the realistic manner in which cameras capture complex lighting environments and combining this imagery with projection mapping techniques [2] that result in a photorealistic environment where variables for different driving scenarios can be changed to create a number of driving environments for testing, evaluating and visual representation.

Background

While it is technically feasible to collect video-realistic recordings of real-world driving situations, and even play back the recordings in high definition and in a calibrated manner where it represents what a driver would see, there are clear limitations. First, the video captured is linear in the sense that it can only be played forward or backward, but always in a prescribed sequence of images. Second, the conditions in which the video was captured represents the only set of conditions that can be played back. Without editing, compositing, or computer visualization, modifying the conditions of the driving situation that was recorded such as a driver's lane position, speed, or other traffic is limited. A third problem is that situations where accident conditions are of interest, such as driving through low lit areas, or testing a driver's perception and reaction to unexpected situations may be dangerous to conduct in a live setting. The methodology proposed in this paper avoids these limitations without sacrificing the quality and visual realism that high definition and high dynamic range video recording possess. This methodology sets forth steps that allow video realistic footage of driving situations to be obtained in a manner that maximizes both safety and controllability of the driving variables that are of interest in the testing. Primarily this is accomplished by separating the vehicles from the driving environment when collecting video realistic footage, and then combining the data that was collected in separate settings back together, using computer modeling and visualization techniques. Since the data collected is maintained throughout the process as video realistic imagery, the ending quality is also video realistic. Further, since the environment is eventually a computer generated environment, controlling and varying the driving parameters are safe and feasible. To test and demonstrate the methodology described in this paper, several scenarios have been presented that describe the steps for collecting and processing the data into a final customizable computer-generated driving scenario that is also video realistic. The following is a general list of the steps involved in this methodology:

a. Collect video footage of the driving environment
b. Collect geometry data of the driving environment
c. Collect video footage of the vehicles under a variety of lighting conditions in a controlled area
d. Collect geometrical data of the vehicles involved
e. Use projection mapping techniques [2] to create a video-realistic computer environment
f. Use computer visualization techniques for creating vehicles with varying parameters
g. Combine the environment and vehicle modeling systems into one system
h. Vary the parameters of the vehicle and scene to generate any number of video realistic simulation scenarios

Baseline Video Footage Used for Comparison

In order to demonstrate how the methodology can produce accurate results, a baseline driving scenario was first captured on video for comparison purposes. This scenario involves a vehicle that is stopped at night on a roadway. Another vehicle is approaching the stopped vehicle from behind. The view represented through video in this scenario is from the approaching driver's perspective. Figure 1 shows a diagram of the layout of the scenario, and Figure 2 shows a daytime photo of the area where the baseline scenario was performed.

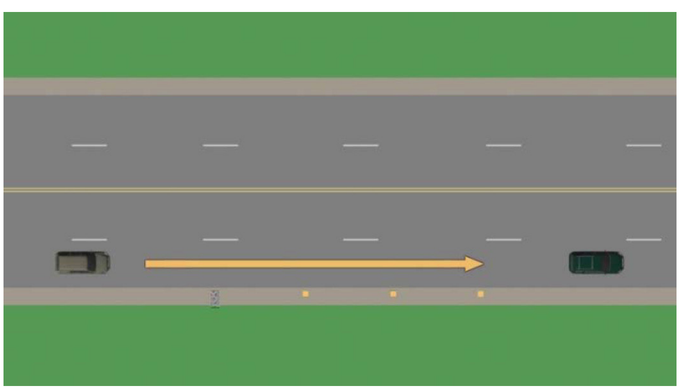

Figure 1. Layout of Baseline Scenario

The baseline footage will be used to compare and evaluate the results of the computer generated version of the same scenario produced through the methodology. The live baseline recording is a linear, unaltered video recording of the vehicle and environment together, while its comparison counterpart produced through the methodology is a computer generated, customizable, video realistic version of the same scenario. After a comparison between the live baseline footage and the computer generated version is performed, the driving conditions of the computer generated scenario are then changed to include different vehicle lighting systems and a different lane position to demonstrate the ability to alter the scenario being represented, and still maintain photographic realism.

Figure 2. Daytime Photo of Baseline Video Setup

In order to obtain the baseline video of the driving scenario, an area was selected and a sequence of events determined that would represent a generic but relevant set of testing conditions. The site includes a hill and a curve that act as visual obstructions for the driver, who is approaching a vehicle stopped in their lane of travel. The video is captured from the driver's view to represent the view available to the driver cresting the hill and rounding the curve. This driving scenario is just one example of a situation where evaluating the roadway lighting conditions, vehicle conspicuity, site lines, visibility and driver perception and reaction would be of interest in a study or demonstration. Figure 3, below, is a site diagram showing the general area used in the study, and the path of travel and location of the vehicles involved.

Figure 3. Aerial and direction of travel for vehicles

In addition to setting up the testing site and the involved vehicles, and defining the driving scenario, equipment was used to calibrate the video footage, and to obtain the recording. Figure 4 shows the equipment used in the study. A complete list of the equipment shown in Figure 4 has been included in the references [4].

To obtain the highest quality footage, and record a view where the lighting, colors, and values of the recording are representative of the actual scene when viewed live with the naked eye, a Canon C100 HD video camera and Atomos Shogun field monitor were used in conjunction with devices that enable calibration of the video image prior to recording. The calibration process described in this paper relies on techniques from previously published literature [5,6,7]. Augmenting these techniques is a quantified approach where light values are measured at the scene using a Konica Minolta LS-100 luminance meter. These luminance values are compared to the corresponding luminance values of pixels of the recorded footage to measure how the distribution of light values across the recorded field of view compare to the same light recordings at the actual scene. In general, the calibration process involves using a field monitor, which is held in the hand, and used as a visual comparison to what is observed with the naked eye. An observer looks into the monitor that is showing a live view of what the camera sees. The observer can oscillate between viewing the monitor and viewing the real world, adjust settings on the camera such as the aperture, shutter speed, and ISO settings until a comparable match between what the monitor represents and what one observes in the actual world scene are the same. This approach has been effectively demonstrated in previous studies [8]. In addition to this step for calibration, the paper presents quantified results that compare the actual light measurements taken at the scene to comparable light measurements in the digital image to evaluate their similarity.

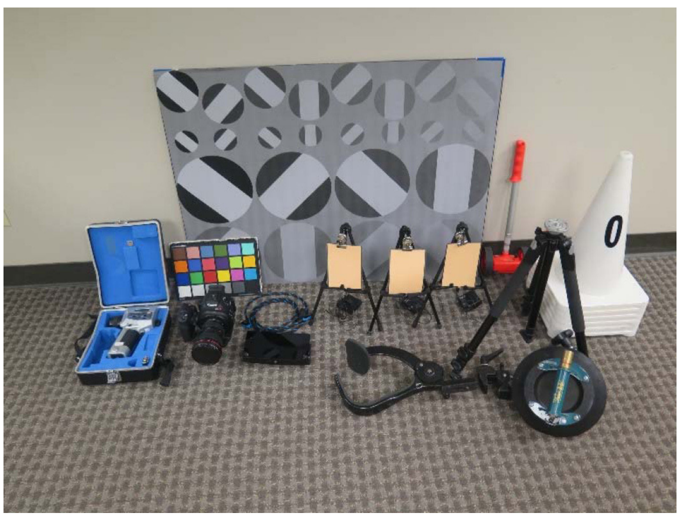

Figure 4. Video Capture and Calibration Equipment

Figure 5. Calibration Equipment at the Testing Area

To calibrate the camera at night and at the scene using the field monitor, a calibration chart with varying values and spatial frequencies was utilized along with three LED markers. These devices are shown setup in the testing site in Figure 5. The calibration chart uses a series of values from light to dark so that, when viewed in the monitor, adjustments can be made to the camera settings so the values and spatial frequencies observed with the naked eye are commensurate with what is represented in the monitor. In addition to the chart, LED lights are placed at varying distances to further add markers that allow calibration of the field monitor to what is observed with the naked eye. These LED markers are also used in obtaining luminance measurements for quantifying the difference in light values across the entire digital image. By using the calibration method described above, and with the addition of LED markers that allow quantifying the comparison of the digital image to real world measurements, a calibrated image can be captured.

Figure 6. Nighttime Digital Image

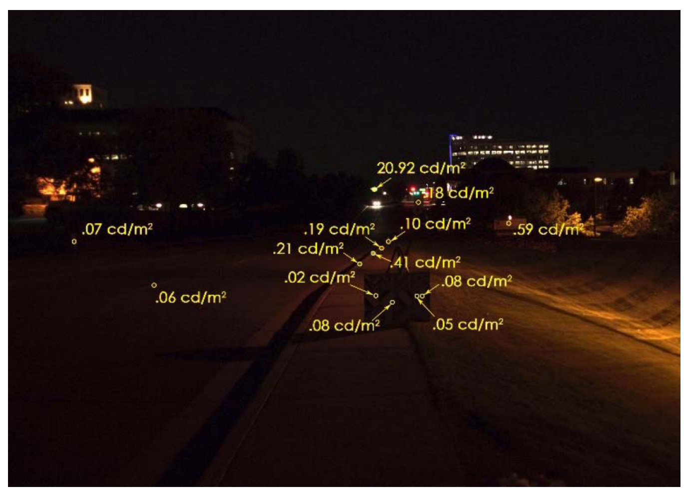

Figure 7. Nighttime Image with Luminance Measurements

To evaluate and quantify the real world light measurements with the digital representation of those light value, an image is captured at the scene, and from this same vantage point, light values are recorded using the luminance meter. These measurements are recorded in cd/m^2 and represent a range of the darkest and lightest values in the scene. Figure 6 is a digital image captured at the testing site, and represents the vantage point from which the digital image was calibrated. Figure 7 is the same image, but with notations showing the luminance measurements taken during the calibration process that are later compared to corresponding light values in the digital image. The results of the comparison between real world light values and light values measured digitally using Photoshop CC are shown in Figure 8.

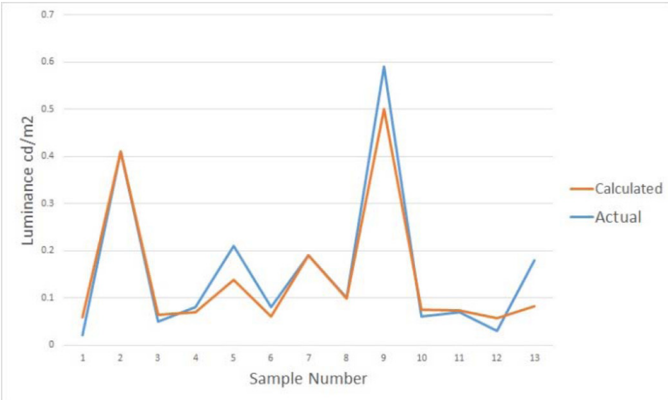

Figure 8. Actual v Digitally Measured Luminance

Several photos are included in Figure 9 to show the camera setup, camera mount used to obtain footage, and the Atomos Field monitor being used in the calibration process.

Figure 9. Camera Setup

In this study the camera settings used to create a calibrated image were f4, ISO 4000, and a shutter speed of 1/125. The field of view of 60 degrees was used, representing a binocular viewing field that includes both the a-pillar and rear view mirror [9], and approximates the degree of field consistent with a forward looking view without head movement [10,11,12]. It is important to note than when playing back the video footage, the field of view determines the width of the display that it is being played on and the distance that it would be shown so that the objects in the playback are the correct scale. This relationship can be defined by the following equation:

$$\tan\left(\frac{1}{2}\theta_{fov}\right) = \frac{\frac{1}{2}y_1}{x_1}$$

(eq. 01)

Where θ_{fov} is the field of view of the camera, y_1 is the width of the screen on which the video is being displayed, and x_1 is the distance the screen is from the viewer. The field of view of a video recording is typically known, as is the size of the screen that it will be shown on. The resulting variable, how far away to view the screen can then be solved as:

$$x = \frac{\frac{1}{2}y}{\tan\left(\frac{1}{2}\theta_{fov}\right)}$$

(eq. 02)

The relationship between the viewing size, viewing distance and the camera's field of view can be represented graphically. As shown in Figure 10, the farther away the screen is from the viewer, the larger it would need to be to maintain the same scale of the image.

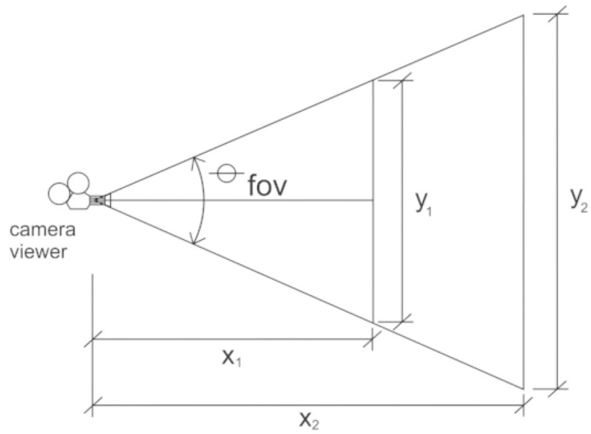

Figure 10. Graphical depiction of playback scale

With the camera and field monitor calibrated to represent the lighting conditions and visibility similar to the naked eye, the driving sequence is captured on video, using a frame rate of 60 fps and HD resolution of 1920 x 1080. Figure 11 is a series of still images from this calibrated nighttime video showing a view available to the driver approaching the stopped vehicle. After obtaining video of the baseline sequence, the testing methodology described in the introduction is utilized to create a computer generated version of the same driving scenario.

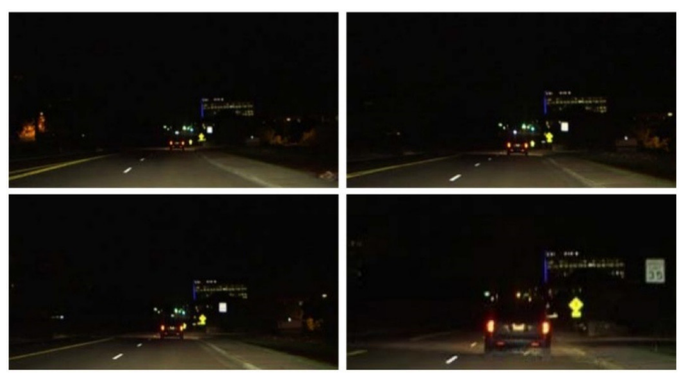

Figure 11. Video Stills from Baseline Footage

Testing the Methodology

a. Video Footage of Driving Environment

The first step of the methodology, collecting footage of the environment, is relatively easy in this case since the camera was already calibrated to record the driving scenario when the vehicle is stopped in the lane. Hence, the same camera settings and setup are used for recording the environment without the vehicle present. This footage will be used as a projection map for the computer generated scene of the geometry such that a user can then change variables such as the vehicle's location, vehicle parameters or vehicle type, or driving conditions. Figure 12 shows still images from the calibrated video footage of the environment with the vehicle no longer present.

Figure 12. Video Without Vehicles

b. Geometry Data of the Driving Environment

For the second step, geometrical data must be collected of the environment in which the video was collected. Using scan data technology, the entire scene, including roadway geometry, trees, curbs, and surrounding buildings, can quickly and accurately be collected [13]. Other methods for collecting geometry can also be used, though scanning is one of the quicker methods. For some scenes, the video footage itself can be used to build geometry of the scene, through tracking technologies previously published [1,2]. In this situation, a Faro laser scanner Focus 3D X330 was used to scan the entire scene, as well as a Sokkia Series 30R total station. Figure 13 shows the resulting computer scan geometry of the scene. This data was then imported into computer modeling programs, in this case Autodesk's 3D Max 2015 and The Foundry's Nuke 9, to further develop the modeling components.

Figure 13. Scan Data of Environment Geometry

c. Video Footage of Vehicles in Varying Conditions

The third step of the methodology involves collecting video and photographic footage of the vehicles by themselves, in a controlled environment. For this step, another area was used where the lighting and traffic can be controlled, so that safe and feasible footage of the vehicle can be obtained, with light conditions of the vehicle being varied: (i.e. with headlamp and tail lamps activated, without any lights activated, and with all lamps and hazards activated). Recording these variable during this step allows the use of these varying conditions to be utilized when producing the final computer simulations. This step of the methodology used the same calibration techniques that were employed when calibrating the monitor in the previous section where environment footage was obtained. The setup for this study is shown in Figure 14 and digital images of the vehicle the driver is approaching is shown in Figure 15, where different lighting configurations are shown. This series, shows the vehicle, at a distance of 100', with no lights activated, with running and headlamps activated, and with all lights activated including the hazard lamps.

Figure 14. Calibration Step Setup

Figure 15. From top to bottom, no lights activated, with running and headlamps activated, and with all lights activated including the hazard lamps.

d. Geometry Data of the Vehicles

Like the second step, where scene geometry was collected, three dimensional geometry of the vehicles that would appear in the video is also collected, using the same geometry data collecting tools such as scanners and survey equipment. The purpose of having computer generated vehicles is to enable varying the position, conditions, speed, and appearance of the vehicle in the final computer simulation. When the vehicle is digitized, it becomes feasible to change variables such as color and reflectivity, lighting configuration, and to add or remove items such as signal indicators and markings. Figure 16 shows the vehicle used in the live study, and the digital reproduction of the vehicle.

Figure 16. Photograph and Computer Model of Vehicle

e. Projection Mapping for a Computer Environment

The use of projection mapping technologies to take video sequences and map them to the surface of computer geometry has been described and published in previous literature [1,2]. In this case, nighttime video footage is used to project texture maps onto the scanned scene geometry that was obtained during the second step of the methodology. This method first tracks the position of the camera relative to the scanned scene geometry through video tracking and camera matching photogrammetry. Then, for the sequence of frames in the video, individual frames are projected and mapped to the surface of the computer geometry, such that the geometry, when viewed from a computer generated camera, will show photo realistic textures and lighting, since they are directly obtained from the video frames themselves. It is this projection of video frames that maintains the video realistic quality of the scene environment in the final simulation. Figure 17 shows the process of projecting video frames on to the scanned geometry and Figure 18 shows the resulting video realistic simulation of this environment from a driver's perspective.

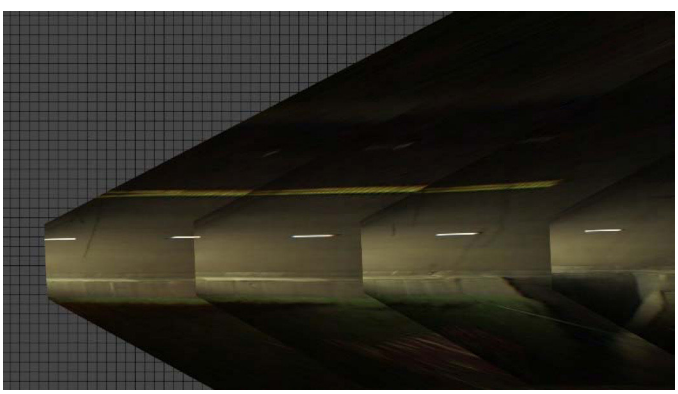

Figure 17. Projection Mapping Sequence on the Terrain

Figure 18. Computer Projection Mapped Environment

f. Computer Visualization of Vehicles

In a similar manner as described in the step above, the vehicles, since they are also computer geometry, are mapped with video and photographic footage obtained from step three where video and photographs were used to document the vehicle in varying lighting conditions. This mapping process essentially creates several variations of the computer model vehicle, each with a different lighting parameter. Color, size, and other appearances could also be modified, since the vehicle is in an editable computer model format. The series of images in Figure 19 shows the mapping process, where digital imagery of the vehicle in different lighting configurations is transferred to the computer geometry of the vehicle. Figure 20 shows the vehicle in its simulated environment and Figure 21 shows the vehicle rendered in the computer environment. This image shows that the computer generated environment and vehicle maintain their photorealism just like the original baseline video footage.

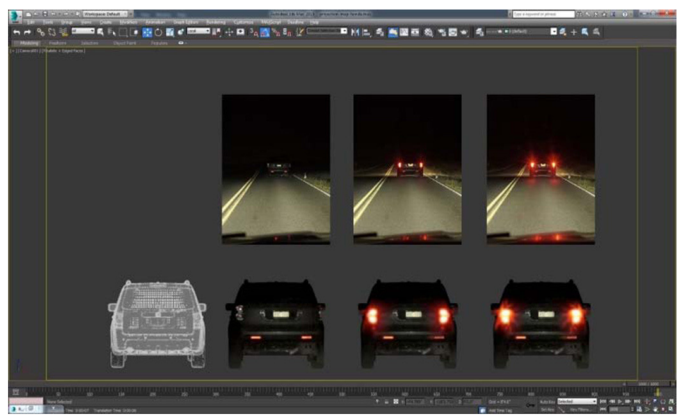

Figure 19. Mapping Process of Vehicle Computer Geometry

Figure 20. Computer Environment with Computer Generated Vehicle

Figure 21. Rendered Computer Environment Composite

g. Combining Environment and Vehicle Systems Together

Since both the scene and vehicle environments are scaled the same, and both contain photo mapped geometry, a computer generated environment can be created incorporating both the vehicle and scene together in the same environment. This environment, because it is a simulated environment, can have any number of variable adjusted digitally. Figure 22 is a series of images showing the computer simulated version of the original baseline video sequence. In this particular series, the vehicle has been shifted to pass the stopped vehicle on the left side.

Figure 22. Moving through the Video Realistic Computer Environment

h. Varying parameters of Vehicle and Scene

To illustrate the usefulness of having a computer generated video realistic environment, a series of images are included in Figure 23 that include some driving scenario variables changed. The top row has the vehicle presented with all of the lights off. The second row has the approaching vehicle in a different lane. Since all of these changes were made by simply swapping out the images of the vehicle, or shifting the camera location in the computer environment, additional time consuming testing was not needed. The following sections show other tests performed using the same methodology, where other vehicles, and driving environments were documented with video, then the geometry of the scene and vehicles scanned and modeled in the computer.

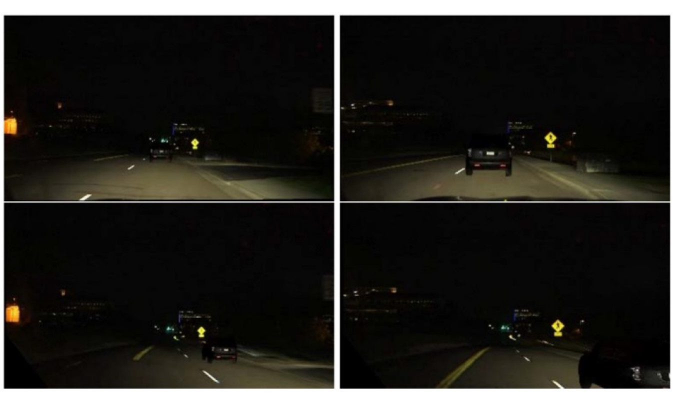

Figure 23. Computer Environment with Driving Conditions Changed

Additional Scenarios

In these additional scenarios, several driving conditions and different vehicle, including a tractor trailer, s were used to run a larger gamut of possible driving scenarios. This was to demonstrate that the methodology would be applicable for numerous driving environments and vehicle models and types. The two scenarios presented in this section include variances such as tractor trailers, left turning vehicles with side lights, and highway environments. Figure 24 shows diagrams of the two scenarios that were tested. From left to right, these are described as the following:

1. Tractor trailer stopped on the side of a highway
2. Left turning tractor trailer

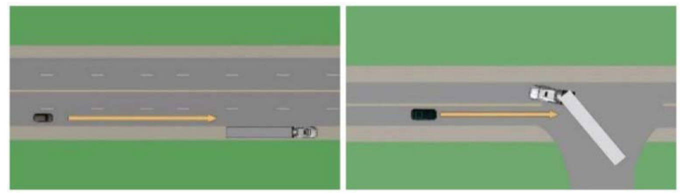

Figure 24. Additional Scenarios with a Tractor Trailer

Each of these tests were conducted using the same equipment and calibration methodologies described in this paper. Images from the baseline video for these tests are shown in Figure 25 and are in the same order of scenarios listed above, starting with the tractor trailer on the side of the roadway.

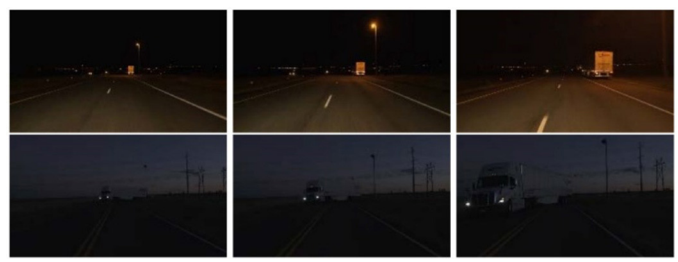

Figure 25. Baseline Footage from Additional Ccenarios

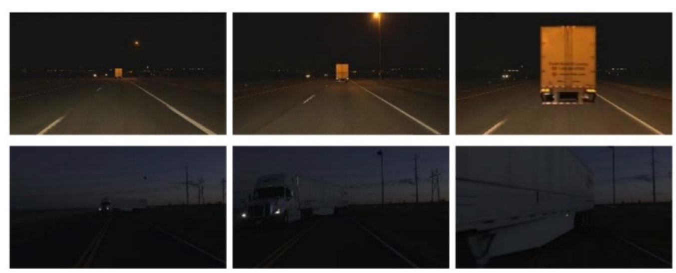

Figure 26. Computer Environment of Modified Sequence

Computer models were created of the scenes and of the vehicles involved, and the vehicles were tested under a number of lighting conditions. The computer models and scene geometry were projection mapped, the resulting computer environment was created and video realistic simulations produced to demonstrate how the variable of the driving scenario could be changed without additional testing. Figure 26 shows images from the simulated environments of these two additional scenarios, each following the same methodology described in this report. Shown in this figure are images from the final composited, simulated videos for both the stopped tractor trailer scenario and the left turning tractor trailer scenario. The top row, based on the scenario of the stopped tractor trailer, has a repositioned tractor trailer in the direct lane of travel up to impact. The second row, based on the scenario of a left turning tractor trailer, has repositioned the approaching vehicle such that impact occurs with the side of the trailer.

Conclusion

This process results in a computer generated environment that is fully flexible, but stills maintains a video realistic quality. Unfortunately, the nature of the subject matter in this paper, i.e. video, pose a particular problem when attempting to represent the final products to which this methodology lead in a printed form. Where possible, still screen captures were used in the Figures to represent images from the video, though with limited success. All the videos produced in connection with this paper will be available online at ww.kineticorp.com. Appendix A has also been created, that has large, full frame images taken from the final composited video for one of the scenarios, showing multiple frames from of the approaching driver's viewpoint, up to impact.

This same methodology, though presented for nighttime driving environments, would be applicable to daytime environments as well. In fact, the daytime environment would be easier to calibrate and track, since the features in the video would be more pronounced, and the techniques for tracking and projection mapping are easier when there is great contrast. Likewise, this methodology is not limited to just vehicles and a roadway environment. If other non-vehicle features were needed in a study or demonstration, these features could be added using a similar process. Barricades, roadway signage, or construction conditions could be added by obtaining reference footage and geometry for each feature that is needed. These scaled models could be added to the environment and be represented under similar lighting, color and contrast conditions, as if these features were present during the original study. Adding pedestrians in varying clothing, for instance, could be performed through the same method to evaluate conspicuity and visibility issues related to pedestrian accidents.

References

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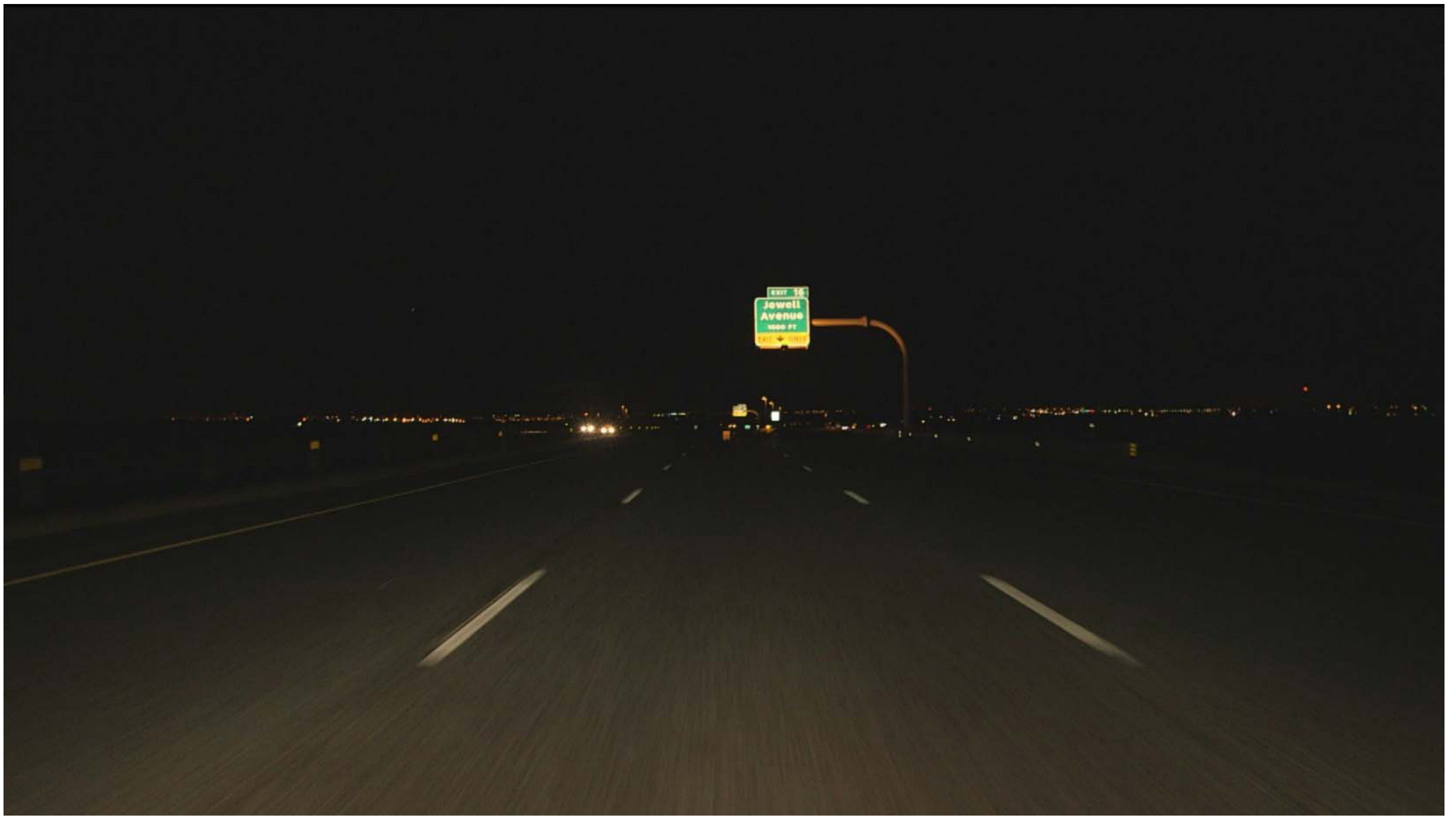
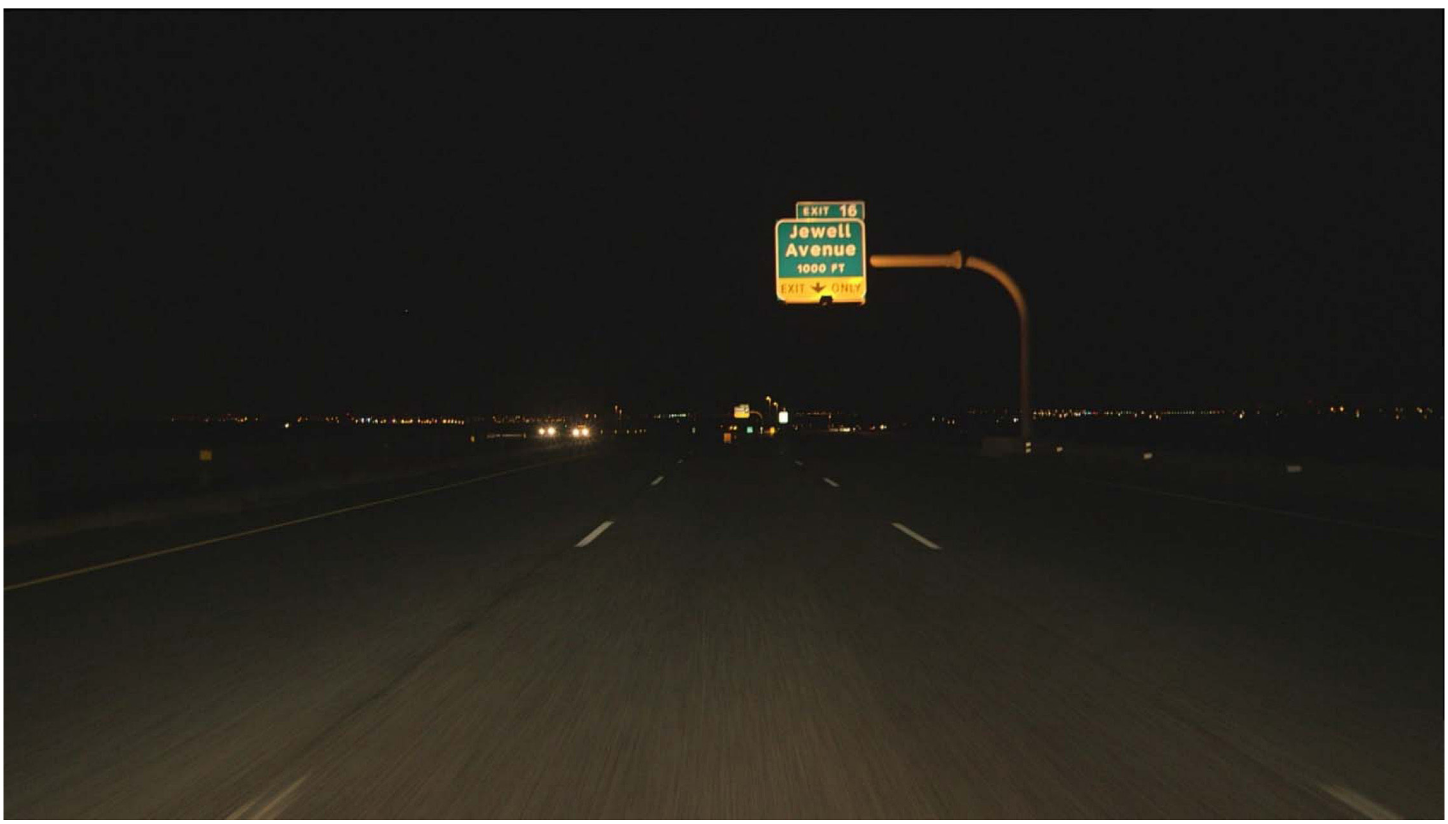
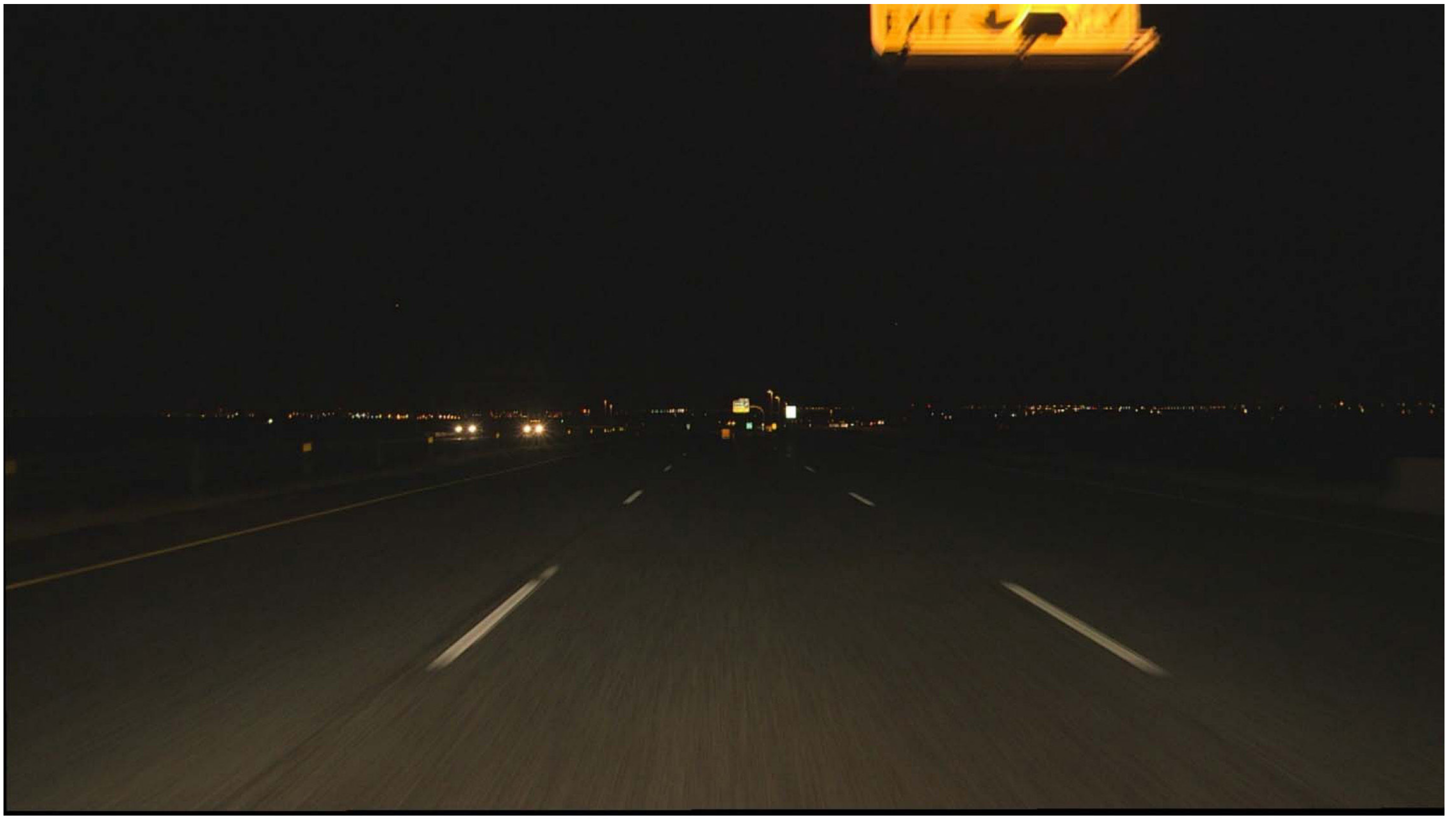
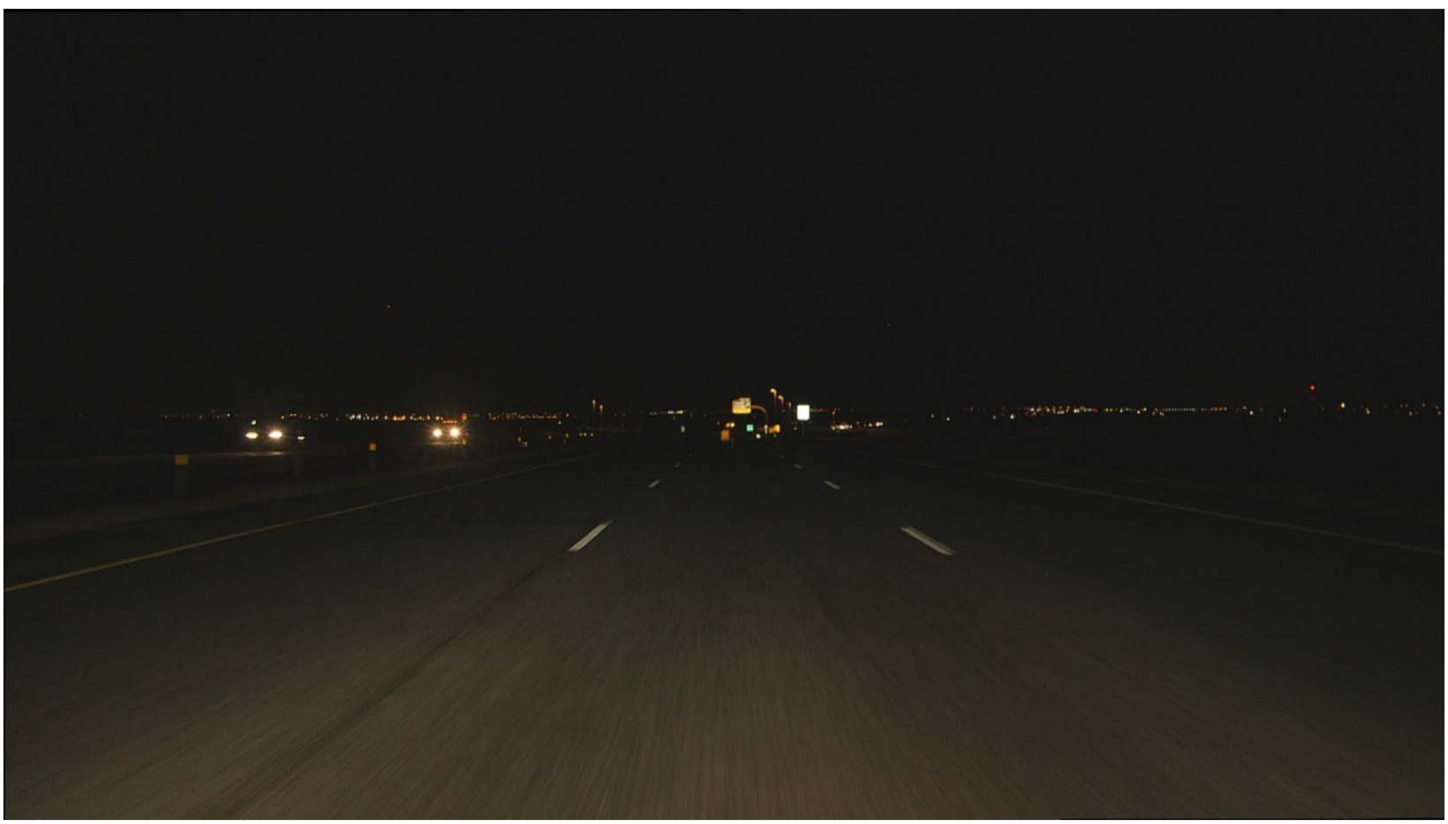
APPENDIX

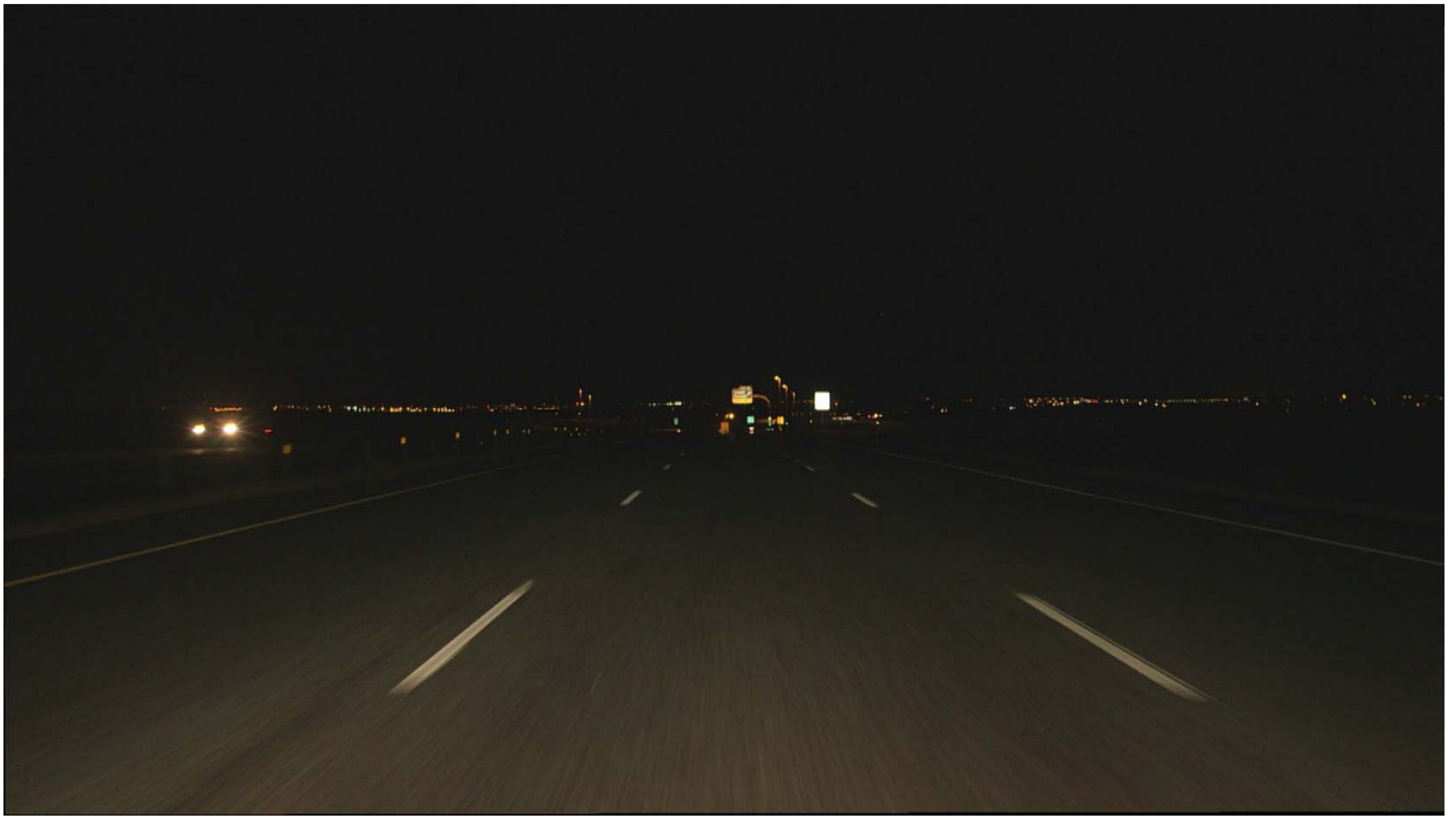
APPENDIX A

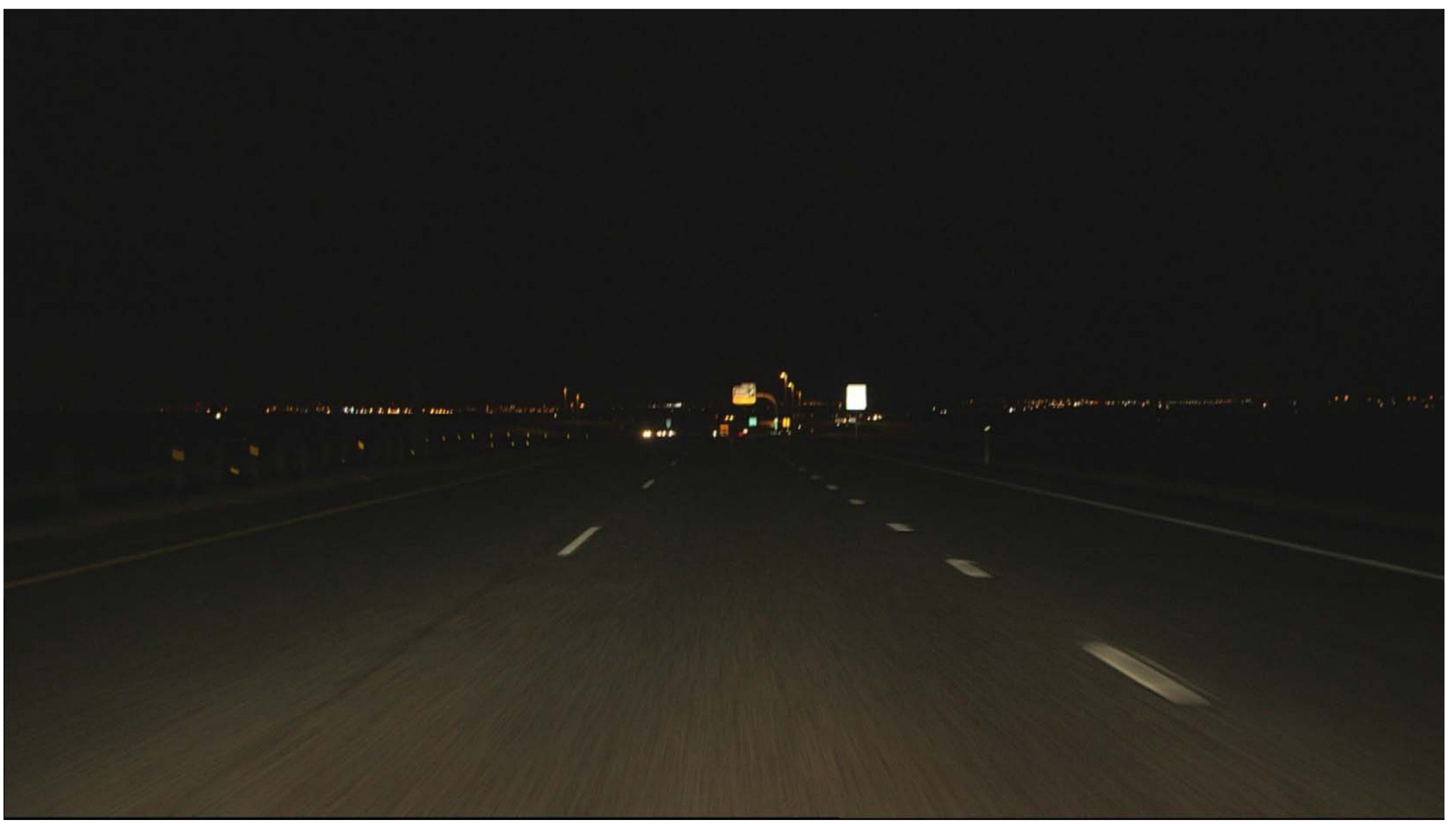


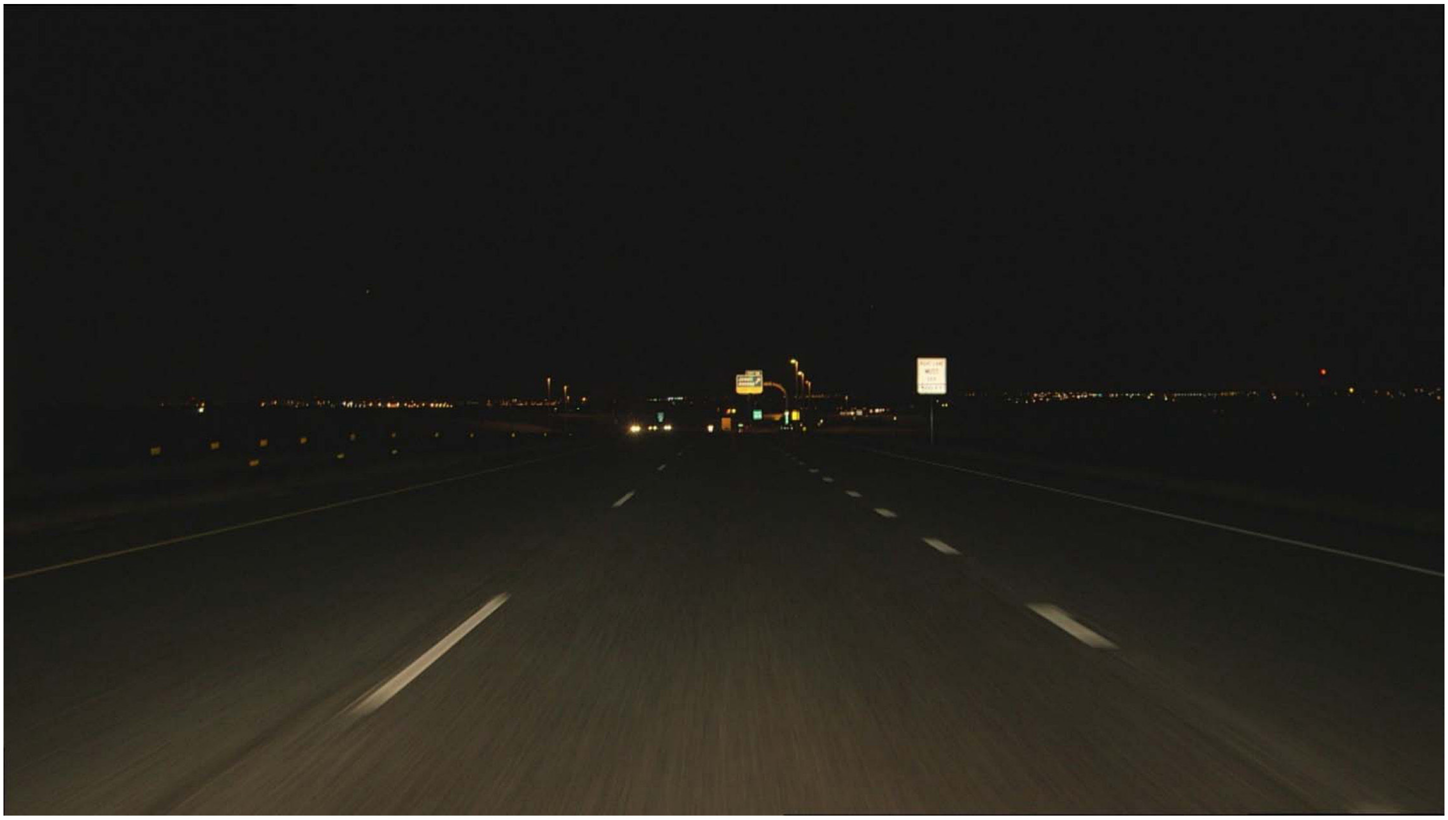


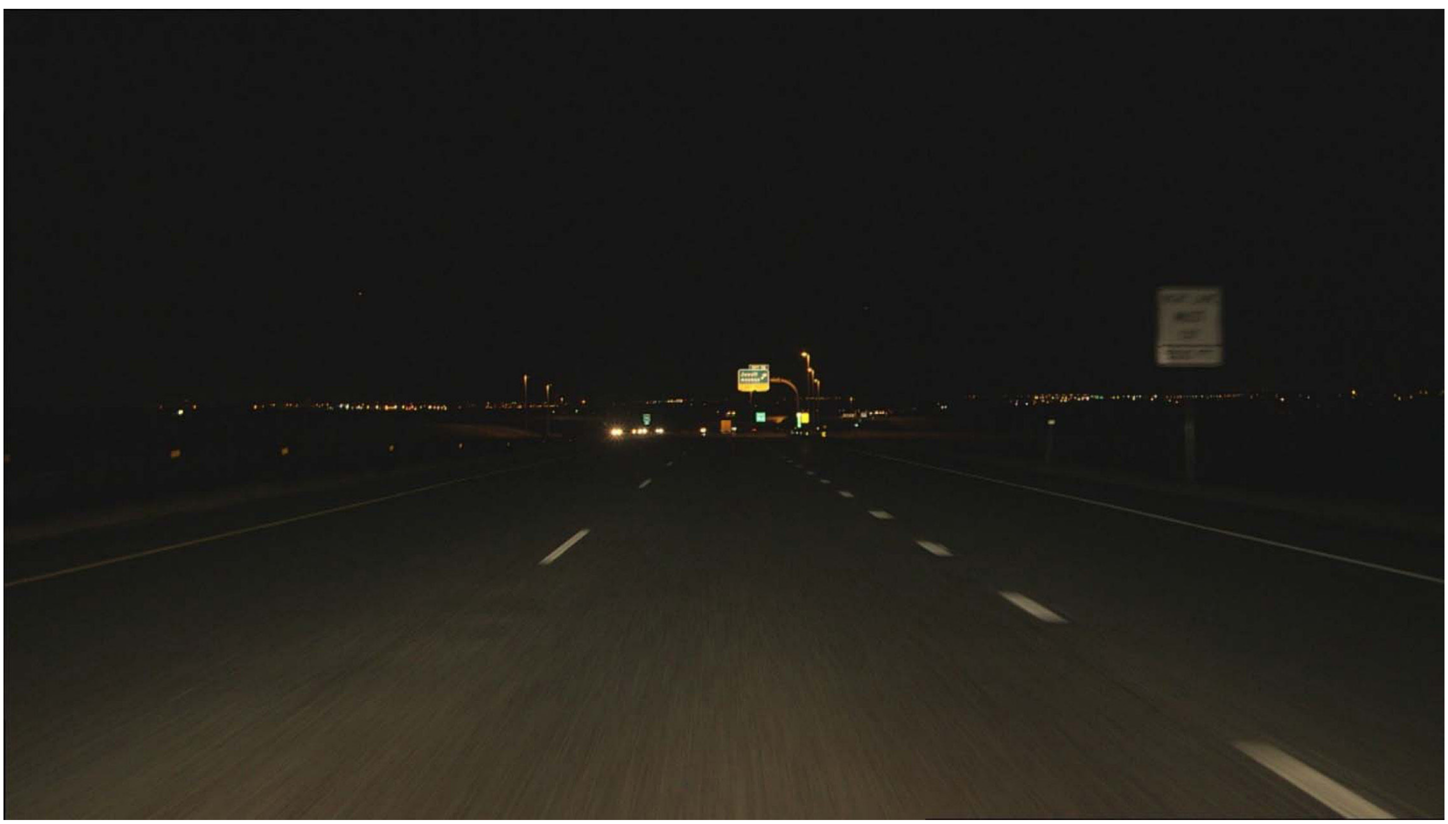


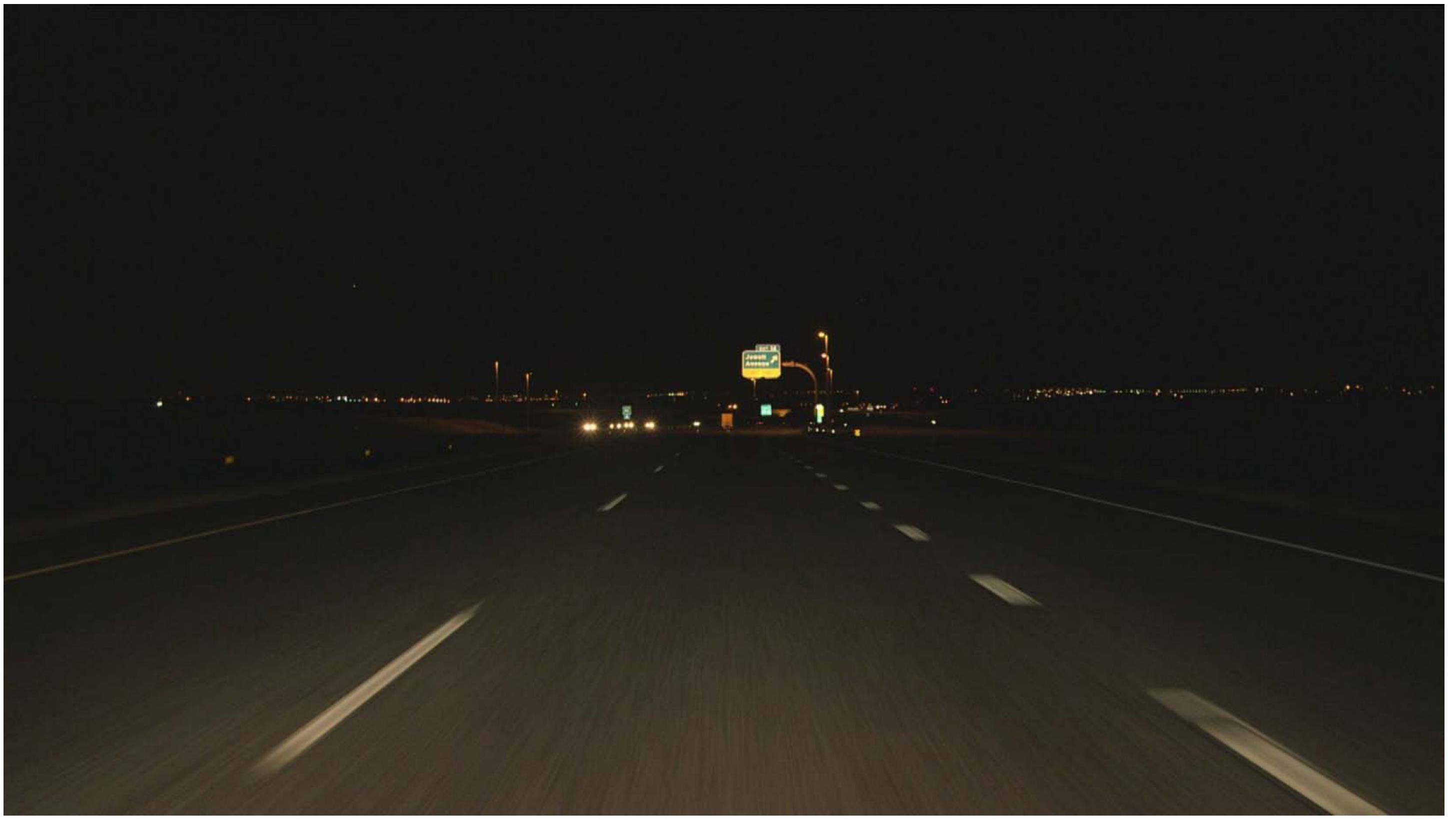


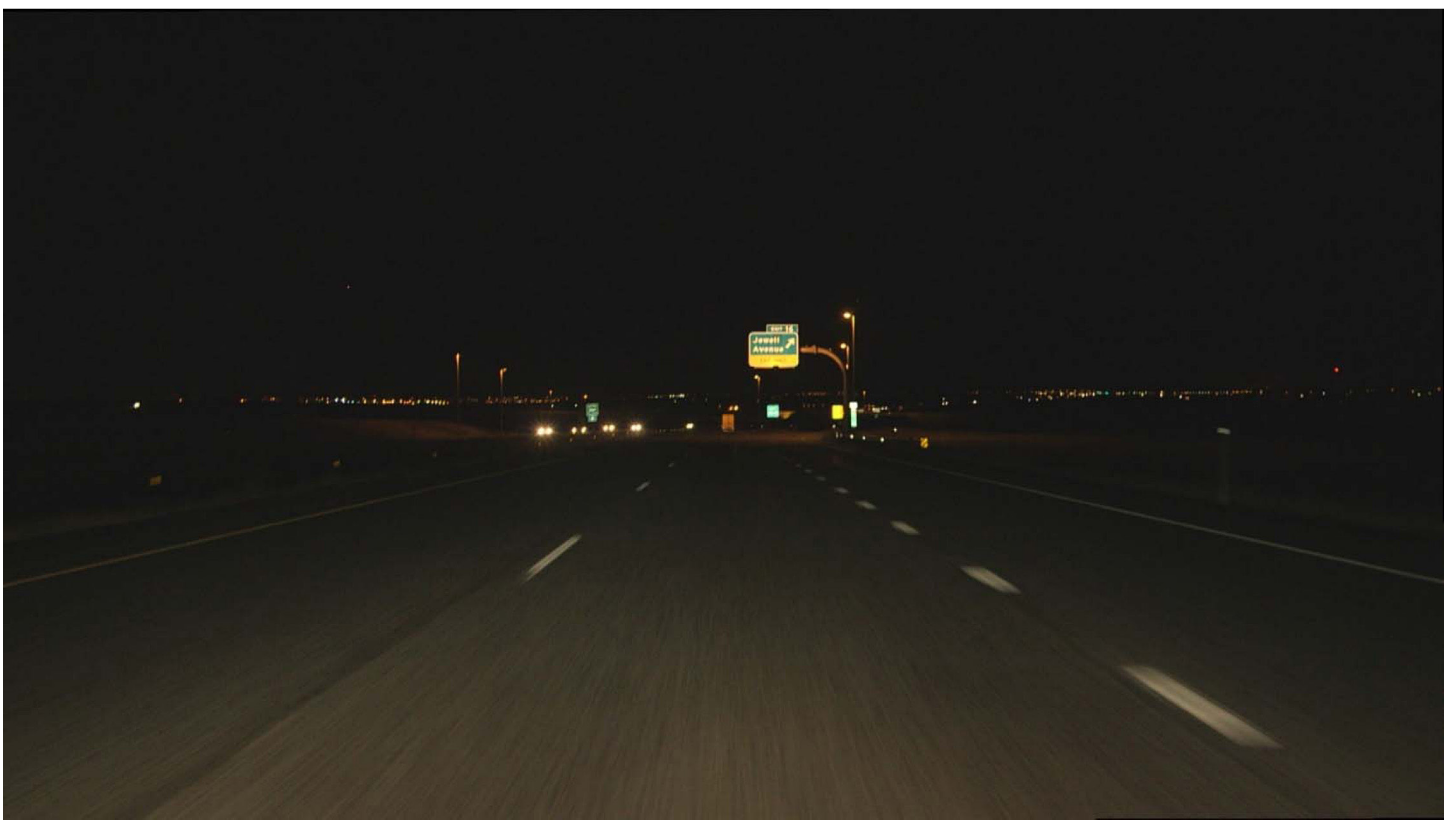








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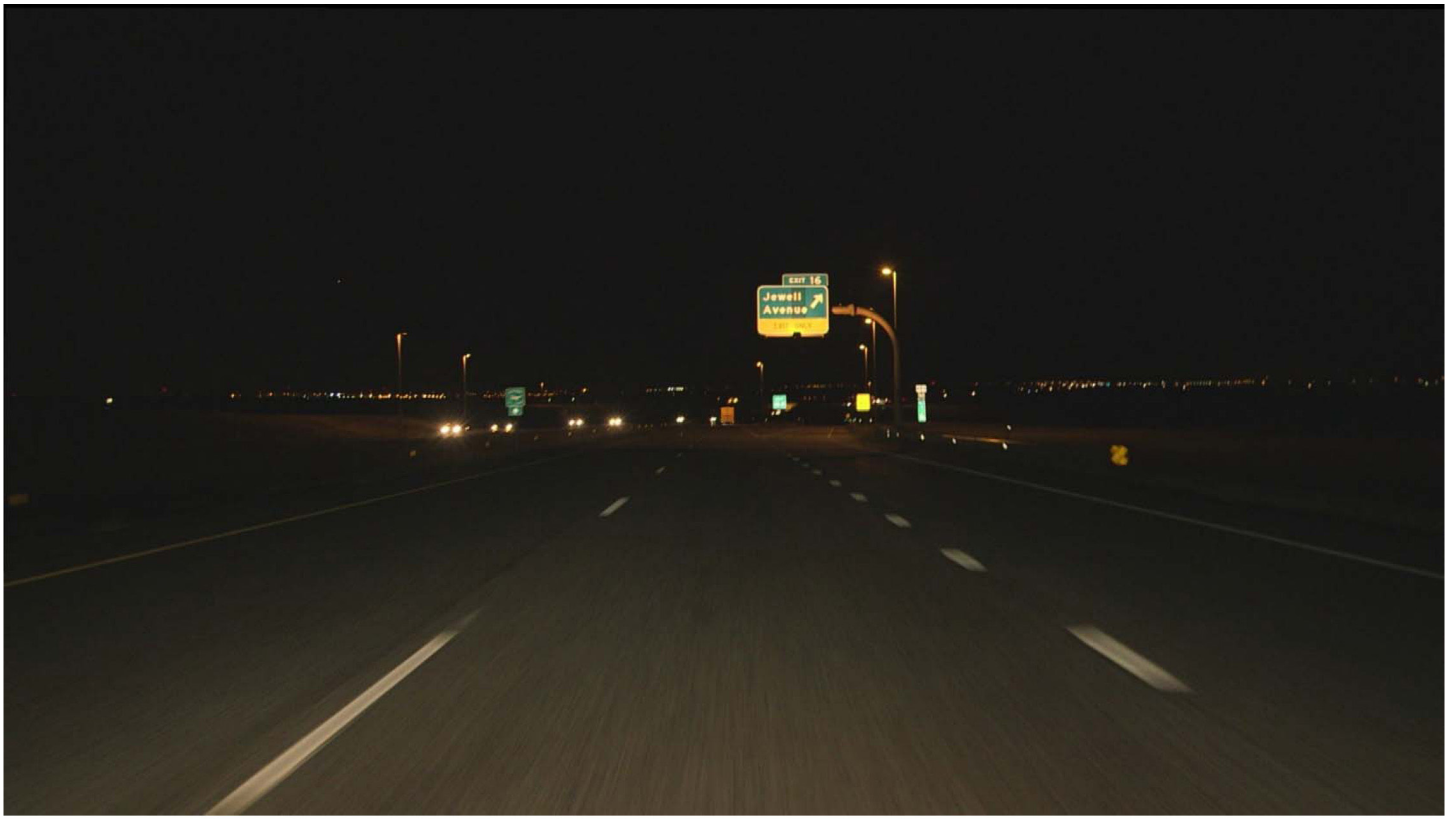
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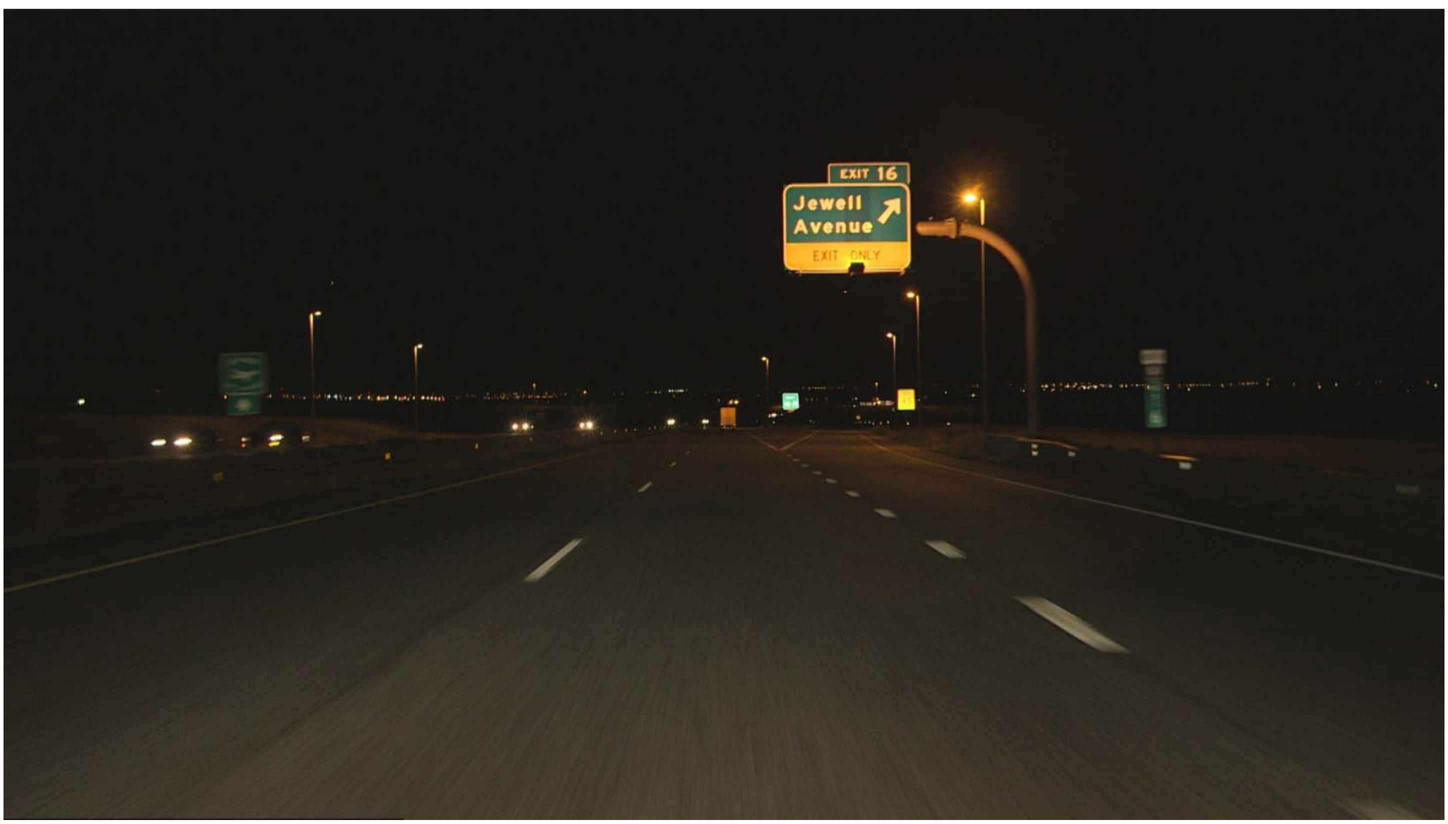
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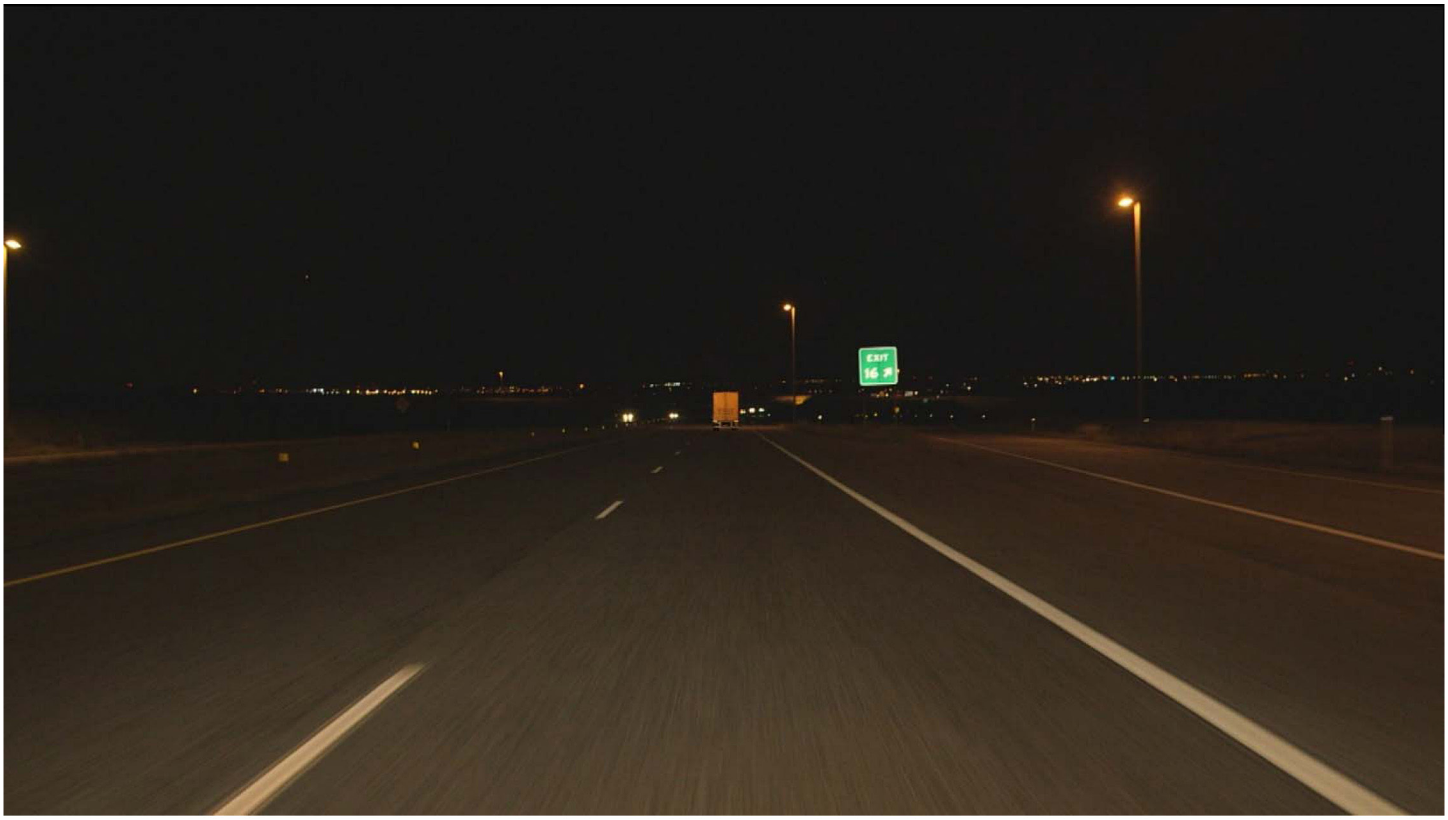
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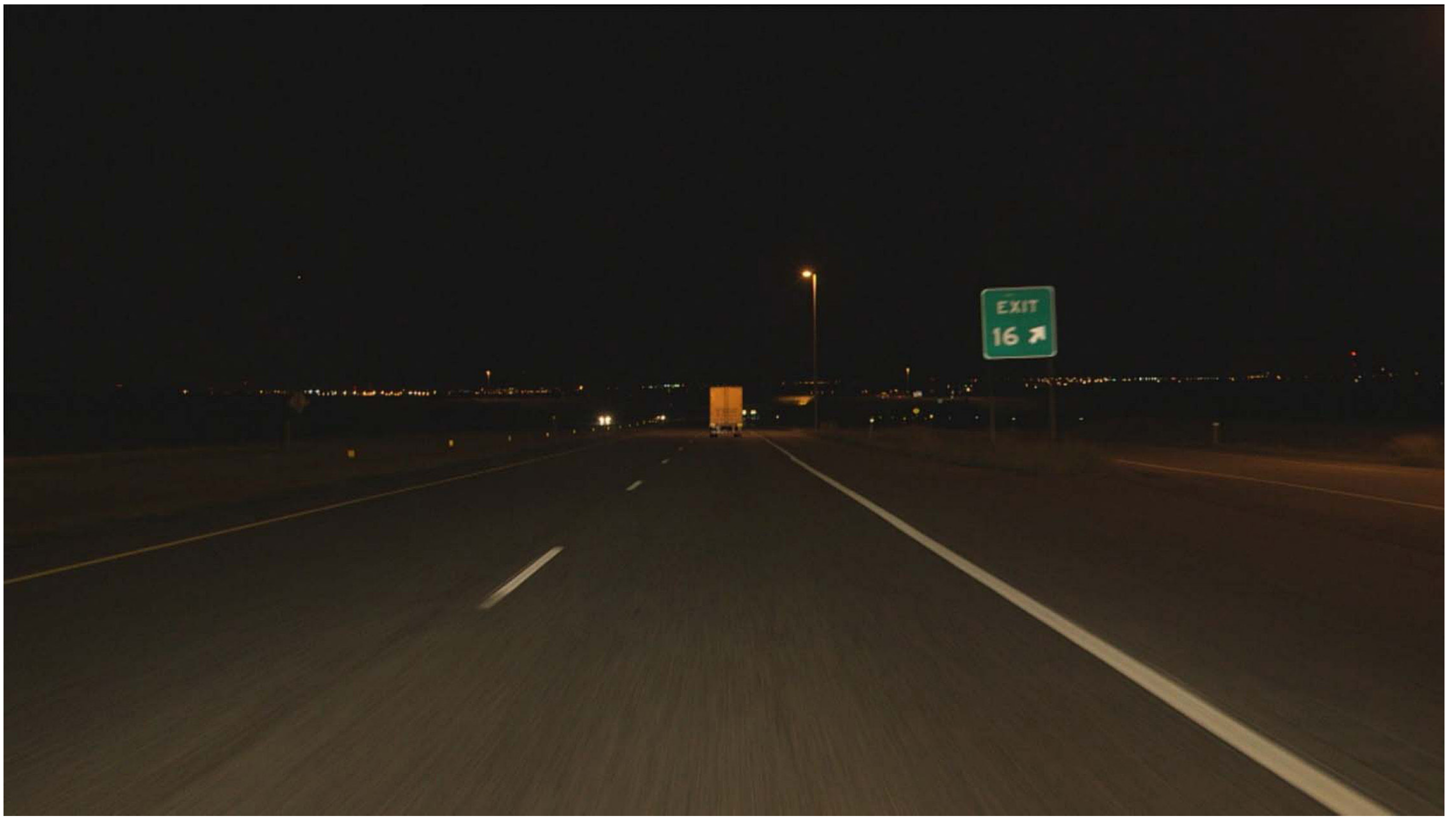
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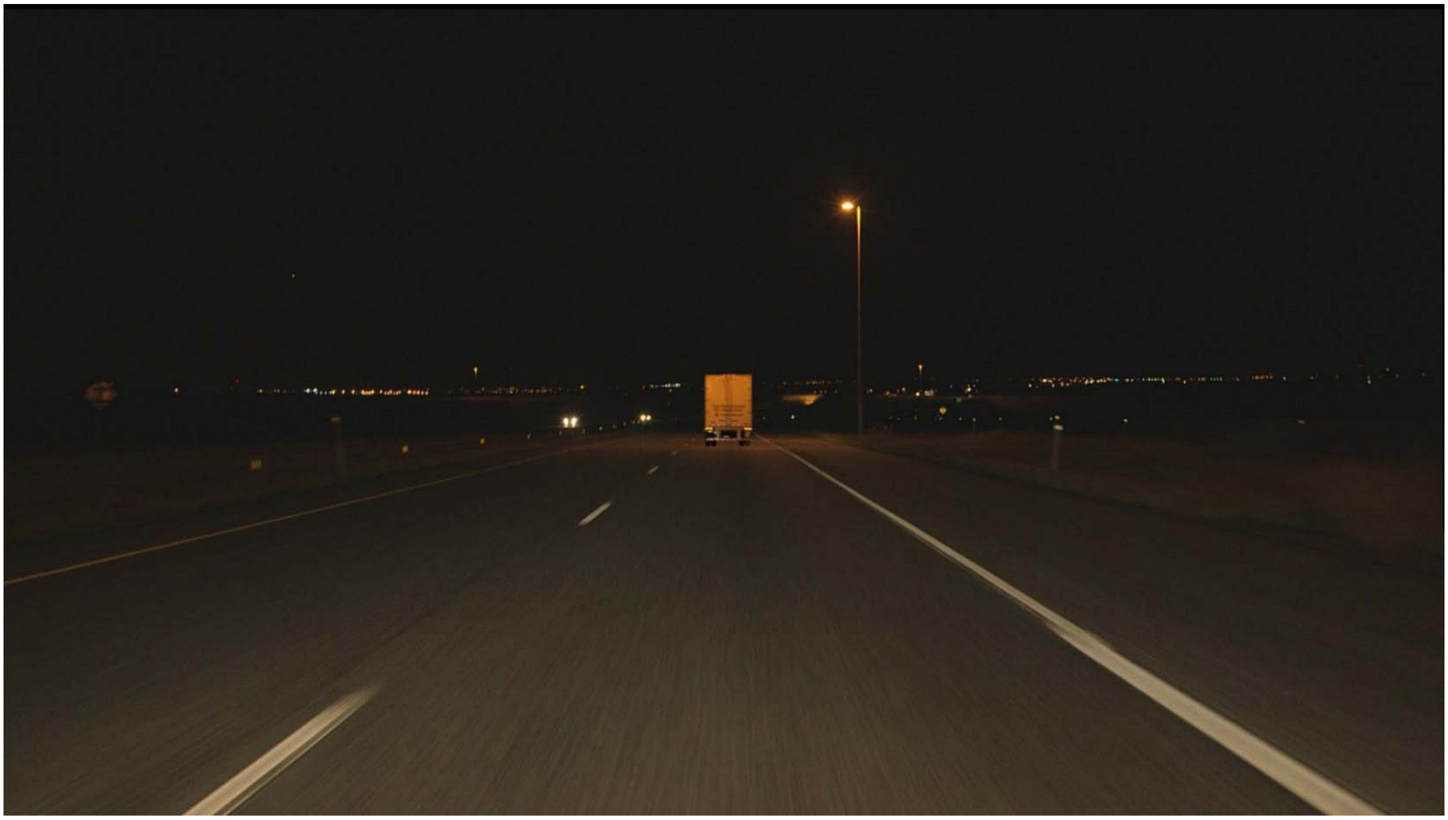

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

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