2021-01-0856 **Published 06 Apr 2021**

Visualization of Driver and Pedestrian Visibility in Virtual Reality Environments

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Citation: Neale, W.T., Terpstra, T., Mckelvey, N., and Owens, T., “Visualization of Driver and Pedestrian Visibility in Virtual Reality Environments,” SAE Technical Paper 2021-01-0856, 2021, doi:10.4271/2021-01-0856.

Abstract

In 2016, Virtual Reality (VR) equipment entered the mainstream scientific, medical, and entertainment industries. It became both affordable and available to the public market in the form of some of the technologies earliest successful headset: the Oculus Rift™ and HTC Vive™. While new equipment continues to emerge, at the time these headsets came equipped with a 100° field of view screen that allows a viewer a seamless 360° environment to experience that is non-linear in the sense that the viewer can chose where they look and for how long. The fundamental differences, however, between the conventional form of visualizations like computer animations and graphics and VR are subtle. A VR environment can be understood as a series of two-dimensional images, stitched together to be a seamless single 360° image. In this respect, it is only the number of images the viewer sees at one time that separates a conventional visualization from a VR experience. The research presented here compares the conventional methods of representing driver and pedestrian views through animations and visualization with a VR environment of the same content. This involves using established methods for conventional visualization and adapting them to the unique requirements needed for a VR environment, including obtaining and processing photographs and video from the driver and pedestrian views. The research evaluates how existing techniques for daytime and nighttime visibility can be adapted to VR environments and discusses the practices and techniques to achieve the best results. An evaluation is also made between the end products produced through conventional visualization media and the VR environment in terms of quality, resolution, clarity, and experience.

Background

Virtual Reality is a fully immersive computer-simulated environment, submerging a user in a 360° interactive viewing area. The concept for this technology is not new, however, and has been experimented with since the 1960’s, first gaining traction with the military allowing immersive remote viewing of “dangerous situations” [1]. Since the 1960’s virtual reality has manifested in various forms, and currently is available to the consumer market through VR headsets and applications that include a fully immersive 360° viewing area and user interactivity. VR originated as a military tool. The military has been experimenting with flight and combat simulation technologies since World War II. The US Navy and United Kingdom military have used VR to train paratroopers without having to waste costly fuel or coordinate battalions of soldiers. In the medical field, VR can transform health training and education for doctors, who can witness an operation firsthand from their own perspective. Another medical use is to provide patients any number of relaxing environments other than the operating room they are actually inhabiting. Even for rehabilitation after a stroke or physical injury, the power of visualizing your body parts working at full functionality can speed recovery time. For disorders of visual development such as a lazy eye (Amblyopia), the technology offers great benefits by making mundane rehabilitation exercises more entertaining and effective. Some VR headsets come equipped with over-the-ear headphones adding an additional three-dimensional auditory experience. The VR environment is also presented in a non-linear timeline. Conventional two-dimensional images, visualizations or animations are primarily linear, having a clear beginning and end, with a predictable time frame between these points. VR environments, however, can be non-linear, allowing a user to interact with the environment thus affecting the sequence of events as the environment responds to the user input. While in the environment, the user can sometimes manipulate, change and control objects or perform a series of actions within the scene, furthering changing the outcome of results in a non-linear timeline. With its more realistic experience of three-dimensional auralization, and non-linear haptic interaction, VR environments have expanded the limitations that exist for conventional visualizations and animations.

However, it is not the technical capacity for virtual reality to mimic the real world in such convincing manner that has developed VR, but rather the consumer demand and desire for more realism in visualization products as a whole that led to the advent of a computer-generated environment that has now expanded to virtual reality. Conventional visualizations, graphics and animations were also developed from the consumer demand for realism in the same research, entertainment, medical or military industries. Thus, while there are important differences between the immersive nature of virtual reality and the linear nature of conventional visualizations, the desire for visual realism is the common driving factor in much of the innovation and development for both technologies. But conventional methods of visualization have already proven to produce scientifically accurate and visually realistic environments. Can these same techniques, already widely employed and accepted, be adapted to create a realistic VR world as well? This research addresses this question since there are technical differences inherent in the virtual reality system. For instance, the technical differences between the VR system and tradition visualization required modifications and adaptations to the existing methods of calibration, recording and postprocessing. Additionally, the final images produced by each system was also different. The differences in the final images were evaluated both quantitatively and qualitatively to understand the underlining limitations or advantages one system might have compared to the other.

Background

The advent of virtual reality technology has presented a unique advantage over conventional video and animation. But beyond the 360° viewing area, and the interactive and non-linear component of the VR environment, the techniques and methods to generate a visually realistic environment are already developed in conventional visualization technologies. Methods and processes for producing video realistic, or photo realistic driver, pedestrian or other observer vantage points have been developed in the accident reconstruction, lighting and visibility, and human factors industries [2,3,4]. These techniques rely on calibrated, high grade source footage or photographs as the basis or background plates for a computer-generated environment. After the source video or photographs have been properly mapped to the computer environment, the environment can be viewed from any number of vantage points, and under varying scenarios, since the computer environment can be customized. Rendering views in this environment require the creation of a camera to represent the view, and since the camera is part of the environment, its motion, field of view (FOV), and target orientation are defined prior to the production of the visualization. This is a critical difference to the VR environment since in a VR environment, the user defines the target orientation by turning their head; it is not predefined.

The research presented here evaluates this point of departure between the technologies. While VR environments contain aspects of a more immersive viewing area, sound, and interaction that are absent from conventional visualizations, both technologies seek to have visually realistic environments. This research examines the application of already existing and proven methods to produce visually realistic and scientifically accurate environments for conventional animations and visualizations, but adapted to the meet the technological requires of virtual reality, that has its own processes, display limitations, and inherent equipment demands that differ from a traditional visualization.

The various steps and methods that would be used to collect, process and reproduce visually realistic material in conventional visualizations are evaluated for their efficacy in being used for the virtual reality environment. Will the equipment used in collecting video footage for conventional visualizations work for virtual reality? Do the calibration processes and stabilization rigs that work well for conventional methods also work effectively for virtual reality systems? Are the post processing images comparable in their quality, resolution, contrast, and clarity? These are the questions analyzed, evaluated, and addressed in this research. After extensive experimentation with varying equipment, calibration methods, stabilization rigs and post processing procedures, the best practices found by the authors are also presented. Comparisons between the final products are also made, evaluating the quality of the final images. Additional discussions include the pros and cons between conventional visualizations and virtual reality in terms of efficacy, use and application, and realism.

Procedure

To evaluate the feasibility in adapting conventional visualization techniques to work within a virtual reality environment, several scenarios relevant to accident reconstruction and issues related to visibility in driver and pedestrian environments were identified. Accurately representing what view was available to a driver or pedestrian prior to a crash can help a researcher or observer better understand the conditions and reasons why a crash occurred. Views representing the driver and pedestrian perspectives were obtained using methods for both conventional visualization systems and for the VR environment. The results of these obtained views were compared to each other based on an analysis of their quality, realism, and effectiveness is capturing the desired view. The difficulties, challenges, or advantages of each approach are then compared. Table 1 represents the scenarios and conditions that were identified, tested, and presented in this research.

Equipment

Conventional Equipment (Non-VR)

Photographs were taken using a professional grade Sony Alpha 7S with a Sony FE 2/28 lens. The Sony A7S is a professional grade, full-frame camera with 12.2 available mega pixels and

TABLE 1 Scenarios for VR comparison

Scenario	Point of View	Lighting	Target
1	Pedestrian - Static	Day	Moving
		Night	Moving
2	Pedestrian - Moving	Day	Moving
		Night	Moving
3	Driver - Moving	Day	Moving
		Night	Moving

a CMOS sensor. It also has an ISO range of 50 to 409,600. Photograph resolution was set to the highest available - 4240 × 2384 px, and photographs were taken at the widest field of view (FoV) or approximately 60° to represent a meaningful and useful driver's or pedestrian's perspective [5,6,7]. A meaningful field of view can contain a range, provided the final display of the image, in whichever system is being used, represents the image at the correct scale [8].

To calibrate the photographs, an Atomos Shogun monitor was used along with published calibration charts representing various tonal changes and spatial frequencies. These calibration charts enable a user to compare the view, contrast, and lighting in the real world to what is represented on the monitor. This monitor has a resolution of 1920 × 1200 pixels.

The conventional format video scenarios were also recorded using the Sony Alpha 7S with the FE 2/28 lens. The ISO varied for each scenario to adjust the exposure to accurately reflect the lighting of that scenario, but the video resolution was set constant at 1920 × 1080. To stabilize the camera for the pedestrian POV scenarios the DJI Ronin a 3-axis gimbal stabilizer was used. Figures 1-5 show the conventional equipment used. In the research presented here, the Atomos Monitor and Sony A7S were both used to capture video and calibrate monitors in both the conventional and virtual reality processes.

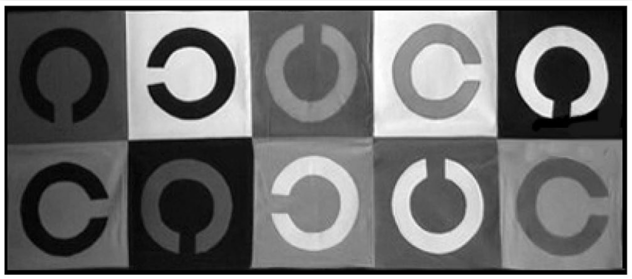
FIGURE 1 Atomos Shogun Monitor

FIGURE 2 Sony Alpha 7S with EF 2/28 lens

FIGURE 3 DJI Ronin 3-axis gimbal stabilizer

FIGURE 4 Grayscale calibration chart

FIGURE 5 Equivalent contrast gradient panel from Crash Safety Solutions LLC



VR Equipment

To capture still photographs in the Virtual Reality processes, the Sony Alpha 7S was used with a GigaPan EPIC Pro V to create the 360° photographs for viewing in VR. The GigaPan Epic Pro V is a robotic camera mount that provides automated control for taking photographs with the proper amount of overlap to create a panoramic 360° image. The same calibration chart was used in conjunction with the Atmos Shogun Monitor to calibrate the 360° photograph.

To capture video in the virtual reality processes, an INSTA360 TITAN camera was used. The TITAN has an ISO range of 100 to 6400, and incorporates eight F3.2 lenses, each with an approximate FOV of 200°. The overlap between videos allows stitching within Insta360 Stitcher. This software allows the final 360° video to be output in h264 and h265 video formats. There are also options for increasing the stitching speed by reducing sampling and quality, but the highest settings are recommended for reliable results. The final stitched 360° video has a resolution of 10560 × 5280 at 30 frames per second (fps). This 11K cinematic camera requires 9 SD memory cards and sells for approximately $15K.

To display the visualizations in a virtual reality environment, the Oculus Go was utilized. This is a portable standalone VR headset that does not require any cord tethering to external computer devices. It has three degrees of freedom (3DOF) allowing users to experience roll, pitch, and yaw interactions, but not translation. A single controller is also used to interact with the presented media. It contains a single 5.5in (13.97cm) display, offering approximately 101° FOV and a resolution of 1280 × 1440 px (per eye). Other headsets, such as the Sony Vive would perform in a similar manner and have similar specifications. However, other headsets were not specifically utilized in the research presented here.

In summary of the equipment used: Figure 6 depicts the GigaPan EPIC Pro V equipment used to generate still photographs in a 360° format. Figure 7 depicts the INSTA360 TITAN which is equipment used to generate 360° video, and Figures 8 and 9 depict the virtual reality headsets used to display the visualizations.

FIGURE 6 GigaPan EPIC Pro V robotic camera mount

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FIGURE 7 INSTA360 TITAN 360° camera

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FIGURE 8 Oculus Go with hand-held controller

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FIGURE 9 Sony Vive with hand-controllers (Not used in this study)

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Description of the Scenarios

As described in Table 1, three different scenarios were conducted to compare visualizations created through conventional equipment and methods, to the results in the VR environment.

Scenario #1 involved a view from the pedestrian's perspective. The setup included a camera on a tripod near an intersection. The camera was positioned looking down the roadway from a pedestrian's POV as a vehicle approached. A single photograph was taken for the conventional method, and a series of photographs were taken and stitched together to create a 360° photograph for the VR method. In this scenario the camera did not move from its location, but a vehicle was included in the view that drove towards the camera. This scenario was examined during day and night lighting conditions.

Scenario #2 is similar to Scenario #1, except that the point of view of the pedestrian is now moving. For the conventional method, the pedestrian's view was obtained with a Sony A7S with mounted on a DJI Ronin 3-axis gimble stabilizer. The rig was pointed towards the approaching vehicle, and the rig carried across the roadway in a crosswalk. A different shoulder mount rig was used for recording the VR method, but to record 360° video the INSTA360 TITAN was mounted on the rig. This scenario was also examined for both daytime and nighttime lighting conditions.

Scenario #3 represents a point of view from within the vehicle. In this scenario, the view is through the windshield, approaching an intersection occupied by two pedestrians, one with a white shirt and one with a black shirt. The video footage for the conventional method was captured with a shoulder mounted driving rig and the Sony A7S. For the VR method, the same shoulder mount was used, but the INSTA360 TITAN camera was used to record 360° video from the driver's perspective. Like the other scenarios, these methods were evaluated under daytime and nighttime conditions.

Each scenario is detailed in sequence in the following sections. For each scenario, and version within the scenario, footage was captured and processed for both conventional visualization and for the virtual reality environment. The final visualizations are depicted, and then an evaluation comparing conventional and VR methods is summarized.

Scenario 1: Static Pedestrian View

Scenario #1 represents the simplest of scenarios. It included a static pedestrian view and since the view does not change, conventional methods will capture this view in a single photograph. The virtual reality methods capture the entire scene in a series of photographs that are effectively stitched together. In short, the conventional method yields on static photographic view, while the virtual reality method captures a 360° field of view from the same static location. This process was performed during the daytime and nighttime, and for both methods and both lighting conditions, the Sony A7S was used to capture images at a resolution of 4240 × 2384 for each image. The primary difference is that in the VR method, multiple photographs were taken using the GigaPan EPIC Pro V. A total of 72 overlapping photographs were taken and stitched together in using Kolor Autopano Giga 4.4. resulting in a single 24678 × 12339 pixel image.

Figure 10 depicts the setups of the camera equipment for both methods. On the left of Figure 10 is the setup for the conventional single photograph, and on the right is the camera mounted on a GigaPAn Epic Pro V which rotates to capture images for 360° field of view. Figure 11 depicts the results of the single photograph using conventional methods for daytime footage, and Figure 12 depicts the multiple photographs collected in the VR method.

FIGURE 10 Setup photos for conventional and VR methods

FIGURE 11 Conventional single photograph of the pedestrian POV (daytime)

FIGURE 12 VR multiple photograph collection (daytime)

Scenario 1: Results and Comparison

The conventional media consisted of viewing the photograph on a 23 in (58.4 cm) computer monitor with a display resolution of 1920 × 1080, which would limit the view of the total available 4240 × 2384 photo resolution. Additional tools for zooming and panning would allow access to this higher resolution data. The 60° FOV, while useful and accurate, is limited in perspective, preventing a viewer from seeing the entire intersection with a single photograph. An advantage of the single photograph conventional method is that it is simple, and easy to obtain and use.

The VR method results in 72 images that were formatted and stitched into a seamless single image using Adobe After Effects. The final image had a total resolution of 24678 × 12339, but the Oculus Go on which the image is displayed is limited to 2560 × 1440 (QHD) for Quad High Definition or 1280 × 1440 per eye. Thus, the display resolution experienced by the user is similar to that of conventional media viewed on a computer monitor. The 360° FOV offered in the VR method gives the viewer the ability to look around the intersection and gain a better understanding of the scene in a seamless and interactive way. Additionally, the VR headset has a fixed perspective for viewing the image. This means that, unlike the conventional method, the scale is always displayed correctly to the user. There is no adjustment needed for the size of the screen displaying the image, or the distance the image is viewed from.

Figures 13 and 14 depict a comparison of the two resulting visualizations. Figure 13 is the conventional calibrated photograph, and Figure 14 depicts the image that is loaded into the VR headset, and hence is displayed in a distorted form when mapped into a flat image for this paper. In a real-world experience, the viewer can rotate to have a correct perspective view of any area in the image. Appendix A is a quantitative and qualitative summary of the comparison between the conventional visualization methods and virtual reality.

FIGURE 13 Conventional calibrated photograph

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FIGURE 14 VR methods 360° photograph

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Scenario 2: Moving Pedestrian View

Scenario #2 includes a moving camera which adds a variable that can affect how the point of view is captured for both the conventional method and VR method. Moving cameras may require shoulder mounting or hand holding equipment. The weight of the camera and carrying rig, and stabilization features can affect the ability to capture footage under extreme circumstances. Frame rate capture by the equipment may also be affected by a moving camera, causing motion blur or other distortions. For these reasons, the variable of a moving camera was added in this scenario for evaluation.

The cameras used to capture the moving view were different. The Sony A7S was still used for the conventional method, but the 360° video needed for the VR method required the use of specialized equipment, the INSTA360 TITAN. The Titan is heavier, and more awkward than the Sony A7S and required the use of a different mounting harness. Figure 15 depicts the setups of the camera equipment for both methods. On the left of Figure 15 is the dual hand-held mount and stabilizer for the conventional method, and on the right is the INSTA360 mount, which is spherically shaped. Figure 16 depicts a series of images from the conventional method. Figure 17 depicts the results of the Titan video that was captured. Since the Titan captures 30 fps from eight different cameras, it is very difficult to depict the video in a two-dimensional image, and hence why the image may appear distorted in this paper. Figure 18 depicts a flattened image of the multiple photographs collected in the VR method.

FIGURE 15 Setup photos for conventional and VR methods

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FIGURE 16 Series of frames from the Conventional method video

FIGURE 17 VR video from each of the 8 cameras at 3 points in time

FIGURE 18 VR methods 360° video while walking (preview)

Scenario #2 Results and Comparison

The conventional method of capturing video with a handheld mount produces clear video with a 1920 × 1080 resolution. In order to track with the oncoming vehicle with a limited FoV, the camera needs to be rotated or swiveled in what is referred to as a panning motion. The user of the conventional handheld mount must make effort in keeping the subject (in this case an approaching car) in the center of view for best results. This rotational motion can introduce motion blur if the movement is too fast. For the VR method, when displayed within the Oculus Go, the 360° video has a lower display resolution of 1280 × 1440 (per eye), but because the camera does not need to rotate to track with the oncoming vehicle, it remains clear throughout the video. This has the benefit of allowing the viewer to experience the vehicle's motion by physically rotating their head to track with the vehicle. Because there is no need to rotate the camera during the recording process, the VR method not only has the benefit of eliminating camera induced motion blur, it also removes concern of having captured the event and having the subject of the video centered appropriately. For daytime testing, the quality of the video was substantially similar, but the primary difference was the constant field of view provided by the conventional method, and the ability for the user to change where they are looking in the VR method.

Testing was also performed at night, where lower shutter speeds are sometimes necessary to increase light to the sensors. With a lower shutter speed, motion blur can be an issue. The nighttime conventional recording used the same Sony A7S with an ISO setting of 25600 and an aperture and shutter speed setting that maximized the clarity of the video. The TITAN was set at its maximum ISO value of 6400. While the camera induced motion blur is visible in the background of the conventional nighttime video, the vehicle being tracked by this camera exhibits less motion blur. The lower ISO settings for the TITAN camera resulted in more noise in the nighttime VR video. These differences are visible in Figures 19, and 20. The top image of Figure 19 depicts the conventional video, showing the vehicle clearly while the background has slight blur. The bottom image of Figure 20 depicts the results of the VR method. Here the background is clear, and the vehicle exhibits some blur.

FIGURE 19 Scenario 2, nighttime video comparison. Conventional (top) and VR (bottom)

FIGURE 20 Conventional and VR video while walking

Scenario 3: Driver's View

Scenario #3 represents the view from inside a moving vehicle. Obtaining video from a driver's perspective involves unique challenges. A view that represents the driver's perspective includes a clear view through the windshield and from a position consistent with being in the driver's seat. As a result, the equipment is typically managed and controlled by the driver. This can be a challenge since the driver must simultaneously drive and operate the equipment. The size, shape and weight of the equipment may affect the performance of the camera and quality of the video that is captured. Further, since the car is moving at a higher rate of speed than walking, there are issues related to capture rate, vibrations, and motion blur that may need to be addressed. For these reasons, the driver's

FIGURE 21 Setup photos for conventional and VR methods

FIGURE 22 Series of frames from the conventional method video

FIGURE 23 VR video from each of the 8 cameras at 3 points in time

FIGURE 24 VR methods 360° video while driving (preview)

view scenario was evaluated for both the conventional and VR methods of video capture.

The conventional method again utilized the Sony A7S camera, but with a shoulder mount that is light weight and able to be stabilized and managed while driving. The video camera for the VR method included the INSTA360 TITAN that was used in the second scenario, to take video footage from eight camera views simultaneously. This camera setup was mounted on the same rig as the A7S, despite its heavy and bulky characteristics. Figure 21 depicts the setups of the camera equipment for both methods. The left image of Figure 12 depicts the conventional driver's view setup, and the right side shows the INSTA360 TITAN camera and mount. Figure 22 depicts a series of images from the conventional method and Figure 23 depicts the results of the Titan video that was captured. Figure 24 represents the image loaded into the VR headset for viewing.

Scenario #3 Results and Comparison

The conventional method of capturing drivers POV video with a shoulder mount produces smooth and clear video with a 1920 × 1080 resolution. The Sony A7S had a FoV of approximately 60°, which captured the scene and the pedestrians crossing the street to the point where their paths would have intersected, without any need to pan the camera and introduce motion blur. The Sony A7S is well suited for low light video recording. For this study, the A7S had an ISO setting of 25600, which resulted in sharp clear video footage. The VR video has a lower but similar display resolution of 1280 × 1440 (per eye) when viewed on the Oculus Go. It also has a lower ISO setting of 6400 producing some visible grain in the calibrated nighttime video. However, the 360° video provides the viewer with a different viewing experience since it is not limited to looking in one direction. Rather, the user can explore the entire 360° FoV through head rotation with the equipment on. For instance, the viewer has the option within VR to look in other directions such as the speedometer, side, and rearview mirrors. Figure 25 shows the conventional and VR video comparison during daytime, Figure 26 shows the same comparison during nighttime.

FIGURE 25 Conventional (top) and VR video (bottom) daytime

Adding CG Elements to VR

The VR method from Scenario #1 which incorporated the GigaPan EPIC Pro V is a great method for capturing and viewing a scene in VR without moving objects. The resulting 360° image can also be used as a backplate for three-dimensional (3D) animations where computer generated (CG) elements can be incorporated into the 360° image. This is accomplished through camera matching photogrammetry and while different than a traditional photograph, the

FIGURE 26 Conventional (top) and VR video (bottom) nighttime

photogrammetric process used to camera match a 360° image is essentially the same previously published process [9, 10]. If the intention to integrate CG elements is known beforehand, time can be saved in the camera match solution by documenting the location of the camera in relation to the rest of the scene. For this purpose, a FARO Focus S350 was used to both map the scene and the location of the camera, resulting in a 3D point cloud environment that included the camera as a 3D element. Using Autodesk 3D Studio Max 2020, an Arnold VR camera was aligned to the camera location within the point cloud environment. With the equirectangular image loaded into the environment background, the camera target was oriented to the horizontal and vertical midpoint of the image and minor adjustments were made to achieve a good alignment between the 360° image and point cloud environment. This is currently an iterative process as 3D Studio Max does not yet support the ability to preview the 360° image within a viewport and alignment can only be evaluated through rendering. Once alignment is achieved, 3D models can be rendered from the camera's perspective and saved as an image sequence to overlay on top of the video footage. Adobe After Effects was used to composite the image sequence on the 360° image and Adobe Media Encoder was used to output in the .mp4 video format for viewing on the VR headset. An additional benefit of the 360° image is that it can be used within the 3D modeling software as a lighting texture map to correctly light the scene with realistic reflections traveling across the vehicle as it drives through the virtual environment. This feature allows the 3D VR environment to be realistic both for daytime and nighttime scenarios. Figure 26 shows the results of this process. In this image, the scene was recorded as a 360° background image, the scan data photogrammetrically aligned to the image, and then a computer-generated car inserted into the 360° image. This series shows in the first image, the car rendered by the lighting derived from the photographs. In the second image, the car is shown as a 3D geometry wire frame to help visually articulate that the car was not in the original video recording. And in the third image, the photorealistic rendered version reappears. Since the CG elements were inserted into the VR environment, the position, orientation, speed or other characteristics of the car can be defined to create any specific scenario for the user to experience and evaluate.

FIGURE 26 Scenario #1 360° photo with CG vehicle

Discussion and Conclusion

The VR environment provides several fundamental differences to conventional animations and visualizations. First, conventional visualizations are displayed on two dimensional surfaces such as flat monitors and screens that have a limit to the field of view that can be shown if peripheral information is needed for the viewer. This limitation is defined by the size of the screen and its distance from the viewer. In most instances, the view can be properly displayed providing a useful visual representation of a drivers view. But under certain circumstances, a peripheral view may be desired, which can include approximately 180° field of view. This is not possible to represent realistically on a flat screen, and is difficult on curved screens, since a user can simply turn their head to look around, thus disrupting any peripheral effect in the image. Since a VR environment continually changes the image shown to the view based on their head movement, this limitation is not present, and the peripheral image is maintained. Second, the VR environment is interactive, and user controlled. Similar to real life experiences, in VR, users can interact with the 3D environment by moving and rotating their heads to look in any desired direction. Users can further interact with the environment using hand-held controllers to manipulate virtual elements or navigate to a desired location or point in time. Third, VR is non-linear, meaning time and space are not preset like an animation which has a beginning and ending. Instead, the user interfaces and interacts with the environment, manipulating, changing, and determining, to some degree, the story that unfolds and is experienced. The user does not have to be passive, but rather can participate in the storyline, much like the real world.

Another limitation of conventional animation resolved by Virtual Reality is the development of haptic, auditory, and visual sensory combined into a single unit. Headsets designed for VR add to the auditory experience, which, in turn, enhances the experience of action and space with a haptic experience of holding devices that represent objects in the virtual world such as tools, controls, or weapons. In the headset, the sense of hearing and touch can be incorporated into a single cohesive experience.

In the field of forensics, there are specific applications of VR that may be helpful. First is the use of VR by experts or analysts. In cases where the actions or inactions of someone in a specific circumstance or environment are at issue, it may not be possible for an expert or analyst to evaluate what the appropriate actions might be, since they were not in the mind of that person at the time of the incident. Efforts to recreate the incident at a scene may not work, since the scene may have changed, or the situation may be too dangerous or dissimilar to recreate. By building the incident in a virtual environment, an expert or analyst can have a substantially similar experience and draw conclusions with a more solid foundation.

A second application in forensics is using VR to conduct research. In cases where there is not an on-point research study for comparison or data, VR can be used to generate research results. This is also true of conventional recreations, but in VR, data can be readily collected from participants through the headgear, as the movement, actions and decisions can be tracked and recorded. The results of this study, since it is a specific, on-point examination of the issues of the case, can be used as foundation by an expert or analyst in determining the reasonableness of someone's actions in the actual case.

The third, and perhaps most obvious, is the use of VR for juries. Images displayed on two-dimensional monitors or screens already allow the juror to experience events from specific points of view. The juror, seeing an image or animation from the perspective of the driver, pedestrian, police officer, or operator of equipment, can better evaluate a person's performance in the context of the facts and issues that have been argued by counsel and experts in the course of a trial. What is limiting in the current two-dimensional technology, however, is a more visceral experience. The viewer is currently limited to the field of view of the image or animation; there is no sound or haptic sensory experience to complete the whole picture. Certain events, such as police use of force cases, vehicular accidents, and construction/industrial accidents that involve sound, touch, or the ability to see a wider field of view, might benefit from the realism of the VR environment. VR allows the jurors to take in the consequences of actions, or inactions, as they have the ability to change and interact with the environment. Seeing a scene or event from the perspective of the persons involved allows a jury to experience the decision-making process for themselves. This role for VR is already taking place, both in the US and internationally [11, 12].

Additional work in the use of VR in a forensic capacity would include evaluating if the tracking system of the headgear is accurate. Additionally, it is worth evaluating if the tracking system is recording movement at a useful sample rate. VR systems have been known to cause disorientation to a user, and further research into the cause, and the potential relief of this effect would be beneficial.

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Conventional & VR Comparisons for Each Scenario

Scenario 1 Comparison

		Traditional	VR
Equipment	Camera	Sony A7S	Sony A7S
	Rigs		GigaPan Epic Pro V
	Cost (Apx.)	$ 2,000	$ 3,000
Media	Resolution	4240 × 2832	24678 × 12339
	FoV	60°	360°
Post Processing	Complexity	Low	Medium
	Software	Photoshop	Photoshop Kolor Autopano
	Formats	.jpg	.mp4
User Experience	Resolution	1920 × 1080	2560 × 1440
	FoV	60°	101°

Scenario 2 Comparison

		Traditional	VR
Equipment	Camera	Sony A7S	Sony A7S
	Rigs	DJI Ronin	INSTA360 TITAN
	Cost (Apx.)	$ 3,000	$ 3,000
Media	Resolution	1920 × 1080	10560 × 5280
	FoV	60°	360°
Post Processing	Complexity	Low	High
	Software	Photoshop	Insta 360 Stitcher
	Formats	.jpg	.mp4
User Experience	Resolution	1920 × 1080	1280 × 1440
	FoV	60°	101°

Scenario 3 Comparison

		Traditional	VR
Equipment	Camera	Sony A7S	Sony A7S
	Rigs	Shoulder Mount	GigaPan Epic Pro V
	Cost (Apx.)	$ 2,000	$ 3,000
Media	Resolution	4240 × 2832	10560 × 5280
	FoV	60°	360°
Post Processing	Complexity	Low	Medium
	Software	Photoshop	Insta 360 Stitcher
	Formats	.jpg	.mp4
User Experience	Resolution	1920 × 1080	1280 × 1440
	FoV	60°	101°

ISSN 0148-7191