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The Importance of Human Perception in Incident Reconstruction and Potential for Misleading Interactive Reconstructions

By Henry "Hank" V. Mowry, PE, DFE (NAFE #1195M) and David W. Ridder

Abstract

A common and key component of forensic engineering and incident investigations is the "reconstruction" component. Reconstructions allow the investigator to build and analyze the incident based upon objective information such as video cameras (including dash cameras, surveillance cameras, and more), post-incident photographs (such as from first responders, eyewitnesses, etc.), physical data (including evidence such as skid marks in a roadway, damage patterns to involved objects such as vehicles, buildings, etc.), and even physical injuries. As reconstructions, software, and technology advance over time, "interactive" reconstructions are becoming increasingly beneficial and prevalent in investigations, allowing the reconstructionist to control and adjust the reconstruction as it is shown. Interactive reconstructions allow the controlling individual to move cameras, start and stop the reconstruction, adjust parameters or variables, and allow analysis of the incident from static and omniscient perspectives. However, such interactive reconstructions can also be misleading. This paper will discuss the often disregarded or misrepresented portion of a reconstruction — what the individual(s) in question "saw" or "perceived" during the incident — as well as demonstrate the potential for misleading interactive reconstructions.

Keywords

Reconstruction, perception, cognition, visualization, interactive, photogrammetry, videogrammetry, forensic engineering, field of view, vision fovea, foveal, macula

Introduction and Background

As defined by the National Academy of Forensic Engineers (NAFE), forensic engineering is "the application of the art and science of engineering in matters which are in, or may possibly relate to, the jurisprudence system, inclusive of alternative dispute resolution." Often, a key component of the "application of the art and science of engineering," particularly as it relates to the jurisprudence system, is incident reconstruction (often called "accident reconstruction").

Incident reconstruction is performed by the investigating engineer to document, compile, and ultimately illustrate the incident, allowing for analysis and demonstration of how it occurred. The reconstruction allows the investigating engineer to formulate and arrive at conclusions or opinions about the incident. Such opinions often include matters of liability, or what an individual (or individuals) "knew or should have known." However, when used improperly, reconstructions may present misleading (or even wrong) information about the incident, such as what information was visually available to the involved party (or parties). Therefore, it is necessary that the investigator understand what questions are being asked, what information is desired, what the investigator can truthfully and reliably reconstruct and represent in the reconstruction, and avoid misleading reconstructions that could be unfairly prejudicial to the trier of fact.

Law enforcement was called to an apartment complex on a report of suspicious activity occurring within a vehicle parked in the parking lot of the complex. Due to high call volumes, law enforcement was not immediately dispatched. A second call was placed to law enforcement, reporting an escalation of suspicious activity within the same vehicle, including a potential physical altercation

Henry "Hank" V. Mowry, PE, DFE, 12503 E Euclid Dr., Ste 80, Centennial, CO 80111, (303) 970-8853, hmowry@knottlab.com

with a second occupant. Law enforcement again did not immediately dispatch officers due to higher priority matters. A third call was placed to law enforcement, where the caller stated that the suspicious individual had a weapon. Law enforcement was then immediately dispatched to the location. The dispatched officers involved more than five police cruisers, a police helicopter, and numerous uniformed law enforcement agents. Upon arrival, law enforcement blocked the sole entrance/exit to the parking lot, formed a perimeter, and began issuing commands. The suspect exited the vehicle, raised his hands, and began communicating with law enforcement. After unsuccessful negotiations, law enforcement fired a less-lethal beanbag round. The suspect entered his vehicle. After a brief period in the vehicle, the suspect started the vehicle, drove forward, and turned away from law enforcement. One law enforcement officer discharged his service rifle into the vehicle as it pulled forward and made its turn. The driver was shot and killed. The law enforcement officer was charged with homicide.

The prosecution's expert produced an interactive visualization that depicted what the law enforcement officer "saw." Tasked by the defense counsel for the law enforcement officer, the authors' firm produced a reconstruction that was developed in conjunction with the expertise of a professor of psychology from a local university. The reconstruction and the testimony of the professor showed that the prosecution's reconstruction was misleading and misconstrued what was "visible" to the defendant. During the criminal trial, both the prosecution (the state) and the defense produced reconstructions of the incident.

Understanding the Question

Though it may seem obvious, the question the investigating engineer is ultimately trying to answer is often overlooked or taken for granted. The investigator often intrinsically and correctly understands what question is to be answered and how a reconstruction must proceed to answer it. However, it is worthwhile to evaluate the ultimate question in greater detail, and — as absurd as it may seem — further ask the question: "But what does that question mean?"

As an example, the authors were recently asked to assist with the reconstruction of an officer-involved shooting (OIS) that had been captured on multiple cameras including numerous dash-mounted cameras (dash cams), body-worn cameras (BWCs), a law enforcement helicopter, and a civilian cellular phone. The OIS matter involved an individual who was shot and killed during an interaction with law enforcement as the individual attempted to flee from law enforcement in a vehicle. The officer who fired the fatal shot was ultimately tried for murder. The question posed was, "What did the officer see?" This question was posed as the jury would ultimately need to decide whether the officer was justified, or at least was not criminal, in firing the fatal shots. The prosecution argued that the responding law enforcement officer should have seen that the victim attempted to flee the scene by turning his vehicle's wheels away from the responding officers to drive down a dead-end drive lane in the apartment complex and therefore posed no hazard to them. If that was true, the officer was not justified in shooting the victim. However, as will be discussed in greater detail, the prosecution's reconstruction was misleading and did not accurately represent what was visible to the officer — let alone the intricacies of what the officer "saw" or "perceived."

Though a seemingly obvious question, one which many forensic reconstructionists may claim to be able to answer through routine and reliable reconstruction methodologies, the ultimate answer to the question is simply incapable of being visually represented. Revisiting the definition of forensic engineering, representing what the involved officer "saw" extends far beyond the application of the art and science of engineering. Human visualization, the anatomy and movement of the human eye, the transmission of information from the eye to the brain, and the analysis and interpretation of that information by the brain are beyond the scope of engineering and require specialized education, training, and experience to evaluate.

Trusted, reliable, and court-accepted methodologies were applied to reconstruct the incident using available information. However, to be able to answer the question of what the officer saw — and therefore how it informed the officer's decision — required very specialized education and knowledge. The defense counsel was aware of this specialty and engaged a professor of psychology at a local university, with the education, knowledge, and practical experience in human vision and perception, to assist in answering this question. The authors worked with the professor to provide a visual representation that approximated what the involved officer could "see" as the officer aimed down the reticle of the department-issued rifle at the victim. However, even with the representation provided, it was still necessary for the professor to provide testimony regarding human sight and perception, as reconstructions are simply incapable, at this time, of accurately depicting innately human physiological matters, such as perception and cognition.

While the request was for a reconstruction of the incident to answer the question of what the officer saw, the prosecution also retained a reconstructionist to reconstruct the incident and present it from the officer's perspective. In response, the prosecution's reconstructionist developed an interactive reconstruction of the entire incident. The interactive visualization allowed for viewing of the reconstructed shooting incident from the perspective of all the other involved officers and the victim. The interactive reconstruction allowed starting and stopping of playback in the virtual reconstruction of the incident, as well as free movement around the shooting scene, enabling the individual running or viewing the reconstruction to "walk" through the incident and start and stop the incident at any time.

At trial, the prosecution represented a first-person perspective from the officer who fired the fatal shot, thus presenting to the jury what the officer "saw." However, the first-person perspective from the officer did not evaluate or take into consideration the myriad factors involved in human sight — let alone human perception — and thus provided a misleading representation to the jury of what the officer saw. Given the prosecution's claim that the officer should have "seen" that the victim was turning away from law enforcement and therefore did not pose a hazard to the responding law enforcement officers, accurately representing what the officer could have seen and perceived was the critical question to be answered.

Therefore, the question of "What did the officer see?" cannot simply be answered, or represented, by a typical forensic engineering reconstruction. The investigating engineer must understand and appreciate their limitations. The investigating engineer must ensure their client understands the limitations of the reconstruction and the areas in which the engineer may opine. It behooves the investigating engineer to set clear limitations on what the reconstruction accurately portrays and to inform the client if additional expertise is necessary to provide opinions on matters outside the reconstructionist's knowledge and expertise.

Reconstructing the Incident

When a forensic engineer is asked to reconstruct the incident, the engineer often relies upon industry-accepted, court-accepted, reliable, and repeatable methods. The purpose of this paper is not to present previously developed, published, and accepted methodologies [1]-[2]. However, in evaluating the limitations of reconstructions, particularly interactive reconstructions, this paper will discuss the reconstruction of the aforementioned OIS and provide comparison to the prosecution's interactive reconstruction to demonstrate the propensity for misleading reconstructions.

When performing a reconstruction, it is imperative that the reconstructionist use meticulous, scientifically proven and reliable methodologies. When an incident is captured on photographs or recorded footage, the art and science of photogrammetry and videogrammetry is often utilized. Photogrammetry is the art and science of obtaining useful, three-dimensional (3D) information from two-dimensional (2D) photographs. Videogrammetry is, in essence, the application of photogrammetry to a recorded video, as a video consists of still images (photographs) captured in rapid succession [3]-[4].

Often, the first step of conducting photogrammetry is to obtain a to-scale, three-dimensional representation (digital clone or model) of the incident location. Regarding the OIS matter discussed previously, the author's firm utilized a Leica RTC360 laser scanner to capture the geometry and configuration of the location where the shooting incident occurred. The laser scanner captures millions, even hundreds of millions, of individual data points measured with very high accuracy (±1.9 mm at a 10 m distance) and density. Once the laser scans are compiled, the resulting product is a three-dimensional model comprising millions to hundreds of millions of individual data points. This three-dimensional model is referred to as a "point cloud."

The incident location was inspected and photographed (**Figure 1**). A total of 12 scans of the incident location were captured (**Figure 2**). Following the shooting incident and prior to the authors' engagement, an independent law enforcement agency also conducted laser scanning of the incident location utilizing a Leica RTC360 laser scanner. The

Figure 1
A general overview of the incident location.

Figure 2
A general overview of the incident location as viewed from the point cloud of the incident location captured through laser scanning.

law enforcement agency captured a total of eight scans. The prosecution's reconstructionist relied upon the scans captured by the law enforcement agency.

After the incident scene was captured with the laser scanner, the authors then utilized the same laser scanner to document two police cruiser SUVs, one of which was involved in the incident and captured dash camera footage during the incident. The prosecution's reconstructionist did not perform this step, which resulted in inaccuracies in the way the police vehicles were represented and in the way/manner in which the defendant was standing and holding his firearm.

The authors then inspected the subject rifle and optic that was utilized by the officer that fired the fatal shots. The rifle was retained in evidence storage. Access to the rifle was provided while the retaining law enforcement agency and evidence specialist oversaw the authors' actions.

It is worth restating that the question to be answered was, "What did the officer see?" The rifle that was utilized by the responding officer was a Smith & Wesson M&P-15 rifle equipped with an Aimpoint PRO (Patrol Rifle Optic) red-dot optic. Given that the rifle and optic would be seen, in part, by the officer who had shouldered (readied) the rifle, it was critical to inspect the subject rifle and obtain an accurate representation of it.

To obtain an accurate and to-scale representation of the subject rifle and optic, the scientific process of "photo-scanning" was performed. Photo-scanning is a photogrammetric process whereby numerous photographs are captured of the object in question. Specific software can then orient the photographs in three-dimensional space utilizing common reference points in the photographs. The software then generates a point cloud from the photographs by, again, utilizing common and identified features within the photographs. This is the same process by which topographical and three-dimensional images can be created using drone footage, satellites, etc. Two-dimensional images are captured of an object. With a sufficient number of two-dimensional images, three-dimensional representations can be created through projective geometry (photogrammetry).

Utilizing the photo-scan of the subject rifle and optic, a point cloud was then generated by the software (**Figure 3**). The point cloud was then "solidified" into a solid, three-dimensional model of the subject rifle and optic (**Figure 4**). The model lacked fine details, but provided a to-scale representation, or digital clone, of the subject rifle and optic. The prosecution's reconstructionist did not inspect the subject rifle or optic, which again resulted in inaccuracies in the representation of the rifle, and, in particular, misrepresentations of the optic. Given that the assertion was made that the officer should have been able to see the front wheels of the victim's vehicle turning away from the officer, what portion of the officer's view/vision would be obstructed by the optic housing, and what

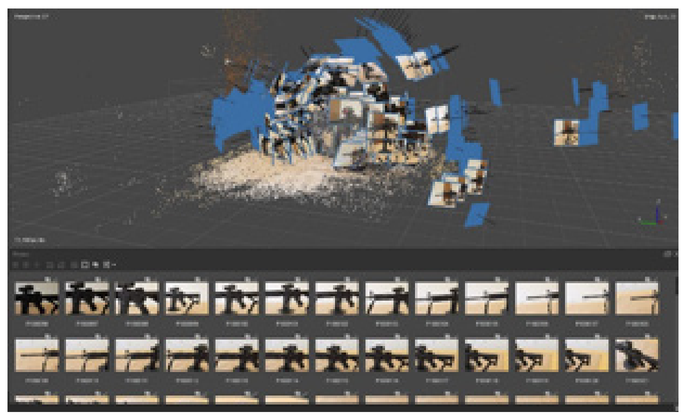

Figure 3
View of the development of a three-dimensional model of the subject service rifle through use of the photo scanning process.

Figure 4
Computer-generated three-dimensional model of the incident service rifle generated from photoscanning.

was visible to the officer through the optic, are of critical importance.

Given the actions described above, the investigation then had accurate, three-dimensional representations of the incident location, the involved police cruisers, and the subject rifle and optic. The next step was to utilize pre-created digital assets (models) of a similar Ford Explorer police cruiser and Smith & Wesson rifle. The pre-created digital assets provided visually accurate representations without requiring the reconstructionist to generate entirely new, labor-intensive models based upon the captured laser scans. However, the digital assets were not accurate in scale or details (e.g., decals, ride height, bumper guard, spotlight, rifle optic housing, etc.). Utilizing the three-dimensional models captured by the laser scans or generated through photo-scanning, the digital assets were scaled and edited to provide accurate, representative three-dimensional models of the involved police cruisers, rifle, and rifle optic.

In addition, the investigation inspected the view afforded to the responding officer through the optic. As previously mentioned, the optic that was mounted to the subject rifle was an Aimpoint brand PRO red-dot. The view through the optic was photographed, and various focal lengths were documented when looking through the optic as it was mounted on the subject rifle. Various focal lengths were photographed to document the change in the size and opacity of the red dot depending on the focal length. In addition, the view down the optic was photographed to document the size and shape of the optic housing (**Figure 5**).

Figure 5
View of the reticle of the Aimpoint brand PRO red-dot optic as viewed from the wielder of the rifle.

To obtain reliable, accurate information from the footage, and therefore to conduct an accurate photogrammetric analysis utilizing the footage, all footage that was relied upon was undistorted. This process has been previously published in multiple articles regarding this process, which will not be detailed at-length in this paper; however, the point cloud of the incident location was then utilized in conjunction with the provided footage to conduct "match moving" or "camera tracking" [12].

In reviewing the footage provided, three cameras were identified that provided the best perspective of the incident (**Figure 6**). The three cameras were identified as coming from two dash cameras from the two police cruisers located nearest to the victim, as well as the civilian cell phone footage. Once the cameras were identified, fixed reference points in three-dimensional space (or "trackers") that were captured in real-life by the laser scan, were identified in the three cameras of interest. Scientific software then "tracked" the reference points throughout the two-dimensional videos. As the points were tracked from the perspective of the cameras of interest, the software solved for the location of the camera that captured the footage. The dash cameras, while fixed, were still tracked to obtain the solved position. However, the cell phone moved throughout the incident; therefore, the position of the cell phone camera was tracked throughout the incident.

At this point, both the prosecution's and the author's reconstructions were largely in agreement. To accurately

Figure 6
Aerial view of the "solved" camera positions throughout the photogrammetric, videogrammetric, and object matching process.

conduct a photogrammetric analysis, a virtual camera must be calibrated and located in three-dimensional virtual space through the aforementioned process. Both reconstructions accurately conducted the camera matching process, resulting in agreed-upon and scientifically validated camera matches.

Once the positions of the virtual cameras were "solved for," the next step in the photogrammetric process was object matching, which is a process where three-dimensional models are placed into the virtual scene by utilizing the calibrated (undistorted) reference footage to match and locate the three-dimensional objects with what is observed within the two-dimensional footage. Utilizing the cell phone footage, dash camera footage, and police helicopter surveillance footage, the scaled three-dimensional representations (digital clones) of the police cruisers were inserted into the virtual scene.

Previously, the prosecution had hired a ballistics expert to evaluate the entry and exit points of the shots fired into the vehicle by the defendant. As part of the ballistics expert's work, the vehicle the victim was driving, a Toyota Prius, was laser scanned with a Leica RTC360. These laser scans were evaluated and determined to be sufficient to scale a pre-created digital asset, similar to what was performed for the police cruisers. A three-dimensional model of the Prius was also inserted into the virtual reconstruction.

Both the defense's and prosecution's reconstructions generally agreed upon the positions of the cruisers and Prius. The positions of the cruisers could be further verified by comparing the "solved for" positions of the dash cameras with where the dash cameras were physically located within the occupant compartment of the police cruisers.

The authors were able to obtain greater accuracy in its reconstruction than the prosecution's expert due to having inspected and scanned the police department's cruisers. Inspection of the department's cruisers allowed for establishment of the actual physical location of the dash cameras in the cruisers, thereby matching the position of the dash cameras with the solved for positions and verification of the solved for positions by comparison of the corrected camera footage. Because the prosecution's expert did not inspect the police department's cruisers, the actual location of the dash cameras within the cruisers could not be verified in the prosecution's reconstruction, resulting in slight differences between the cruiser positions.

Because of the relatively small size of the officer's service weapon, object matching was not primarily relied upon; however, it was utilized to crosscheck placement of the service weapon based upon the BWC footage. The BWC footage from two additional officers was utilized for placement of the service weapon within the reconstructed scene. The BWC footage captured the position and location of the defendant, as well as the position and location of his service weapon, throughout the shooting incident. Reference points within the BWC footage were utilized to place the digital clone of the defendant's rifle within the reconstructed scene. Once the digital rifle clone was placed, the position was further evaluated by examining the undistorted reference footage. The placed digital clone closely matched what was visible in the cell phone footage.

It is worth repeating that a reconstruction of the incident from the officer's perspective was requested to determine what the defendant "saw." To ensure the highest accuracy possible, the officer's "eye relief" was measured. Eye relief is a term utilized to describe the distance between the back of the firearm's optic housing and the shooter's eye when the weapon is shouldered and ready to be fired. The defense counsel obtained and provided an image of the defendant shouldering the subject firearm. For this test, the firing mechanism was removed from the rifle to render it safe and incapable of being fired, and the adjustable stock was adjusted by the defendant to match the extension at the time of the incident. The defendant then shouldered the rifle, and a scale was placed along the rifle to measure the distance between the defendant's eye and the rear of the optic housing. Once this information was provided, a virtual camera could then be placed at the same distance behind the digital rifle clone to provide a view (not vision) down the optic that would be representative of the defendant's view when aiming down the subject rifle and optic. The prosecution's reconstructionist did not account for eye relief or the subject optic.

Misleading Interactive Reconstructions

It is at this point that the prosecution's reconstruction and the authors' reconstruction drastically diverged. The prosecution's expert reconstructed the incident, including from the perspectives of multiple law enforcement officers, and provided an interactive reconstruction (**Figure 7**). The interactive reconstruction allowed the incident to be viewed at varying playback speeds (including slow-motion and paused), at varying angles, from differing perspectives, and allowed the "operator," or individual interacting with the reconstruction, to walk around the incident virtually as the virtual reconstruction was played,

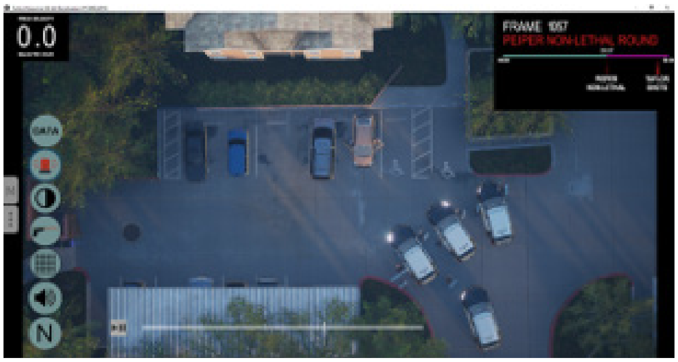

Figure 7
Aerial view of the prosecution's interactive reconstruction.

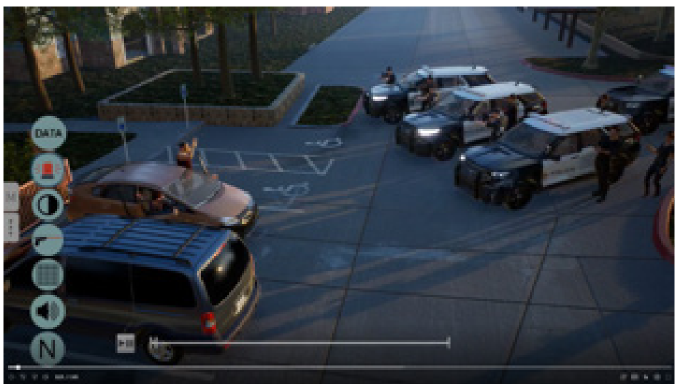

Figure 8
View of the prosecution's reconstruction as viewed from an angle not available to the defendant.

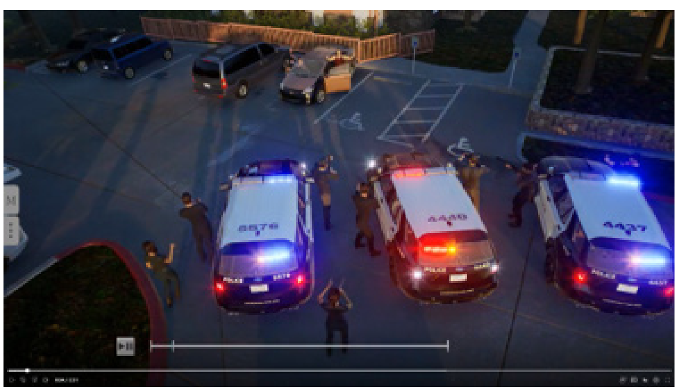

Figure 9
View of the prosecution's reconstruction as viewed from an angle not available to the defendant.

providing unlimited information and perspectives that were not available to the defendant (**Figures 8** and **9**).

Ultimately, the question posed to the jury was whether the defendant was justified in shooting. As such, the matter is best evaluated from the perspective of the individual who acted, not as an omniscient being with a litany of information that was unavailable to the defendant. Although the interactive reconstruction could prove invaluable in answering questions other than what had been asked, such as whether or not the department's response met department guidelines and policies or if the responding officers had positioned themselves appropriately given their training. However, such a reconstruction is neither helpful nor impartial when evaluating the actions of the individual involved if it does not investigate the matter from that individual's perspective. Recall, it was the defendant on trial, not the department; therefore, it is misleading to evaluate the actions of the defendant with omniscient views and information that was not available to the defendant.

The prosecution's reconstructionist did provide first-person perspectives, including from the perspective of the defendant and the victim. However, what was presented was lacking in crucial and critical detail; namely, how human vision functions, what a human "sees," and what that human perceives. Human vision and human perception quickly escape the bounds of engineering and enter the realm of physiology and psychology — a field that requires unique and extensive education and training far beyond the field of forensic engineering.

Representation of Human Vision in a Two-Dimensional Proxy

There are several key problems faced when trying to represent three-dimensional human vision in a two-dimensional proxy. These key issues include:

- Field of view
- Attempting to accurately represent peripheral vision
- Lack of the third dimension
- Determining what the subject was looking at
- Accounting for the viewer's additional perspective

Human vision provides a nearly 180° field of view with both eyes open [5]-[6]. During the reconstruction, a series of images was created with fields of view ranging from 130° down to approximately 20°, with 40° representing the primary visualization presented to the jury. A field of view of 40° is the approximate field of view represented by a 50mm lens on a full-frame camera, which has historically been used by photographers to represent "normal vision."

While images rendered at a much higher field of view are technically more accurate representations of the human field of view, they look very odd to a third party, external viewer because the rifle and optic were hardly visible in these representations. This is partially exacerbated by the viewer's perspective, since they are observing a 2D representation of a compressed 130° view. In other words, what the reconstruction represents is, in essence, a 130°, three-dimensional view of what the officer saw, compressed down to a computer monitor or TV screen, thus resulting in a perceived dramatization of the human field of view, with central objects appearing minimized and distant from the viewer. While technically accurate, viewing such a wide field of view on such a small, targeted surface results in a visualization that appears misleading or distorted.

Another challenge when trying to represent what a subject "saw" or perceived is the lack of the third dimension. Currently, we are limited to two-dimensional images and videos, which don't allow the viewer to clearly determine depth. However, in this case, the subject had stated that he had one eye closed during the event, which allowed the reconstructionist to largely ignore the challenges present while trying to accurately represent dimensional vision/perception in a 2D medium.

Due to the constant scanning nature of human vision, it can be difficult for a reconstruction to accurately determine what specifically the subject was looking at during an incident. This can significantly affect the accuracy and usefulness of these types of exhibits. However, based on testimony, the BWC footage, and the additional circumstances of the case, the reconstruction was performed under the assumption that the subject was looking through the rifle optic and focused primarily on the vehicle and its occupant.

This is a somewhat unique situation. We must recall that, typically, the human eye is constantly moving, shifting from one point of interest to another. For example, when reading this paper, the reader is not just focused on the page, with all words in clear view; the reader's eyes are moving from word to word to word. Therefore, rather than ask, "What did the subject see during the incident?" The question must often be changed to, "What would have been possible to see from a specific point in space and time?" This is consistent with the prosecution's reconstruction, but was not consistent with what the officer saw.

Fortunately, in the situation described above, the authors had the added benefit of knowing the subject was aimed through a rifle scope and that the focus was narrowed on the vehicle and its occupants. This analysis further benefited from working with an expert in human vision, perception, and cognition to aid in analyzing what an individual would be focused on when in a situation such as that faced by the defendant (e.g., aimed down a rifle optic, one eye closed, and focused on a perceived threat).

The authors used relatively simple methods to visually represent and model the "blurriness" (or "lack of focus") and lack of contrast present in peripheral vision. Based on information presented in published literature [5]-[6] and with feedback from the professor, a field of view of approximately 40° was selected as a primary representation for the visualizations. As previously discussed, 40° has historically been used by photographers and other visual artists to represent "normal" vision. With this in mind, the authors employed the use of Adobe After Effects' suite of effects and a black and white gradient map to control the application and falloff of those effects.

The effects were added in two parts — the first part being the "blurriness" of the image, and the second part being the contrast and saturation adjustments.

The blur was applied using the "Camera Lens Blur" effect in Adobe After Effects. This effect can use a black-and-white image to control the amount of blur applied to the affected layers, applying no blur where the black-and-white image is black and fully blurring parts of the image that are white. This black and white image, which will be referred to as a "luminance matte," was generated by using the Gradient Ramp effect and adjusted with Curves effect to control and shape the falloff. The center of the luminance matte was set to pure black to prevent any blurring at the center of the image where the subject's vision would be clear, then slowly transitioned to white near the edges of the frame where the vision would be the least clear.

The amount of blur applied was based on published literature and experimental data [5]-[6] in conjunction with feedback from the psychology expert. Ultimately, the authors' final visualizations were conservative and on the side of creating clearer images with less blur to account for minor eye movements and scanning, even though the subject could be reasonably assumed to have maintained full focus on the vehicle and its occupant. In other words, the visualization contained greater clarity than it would actually be for the human eye in the specific instance reconstructed and experienced by the defendant.

To implement the contrast and saturation adjustments, a secondary adjustment layer was used. The contrast was controlled by another Curves effect, and the saturation was lowered by using a Color Balance effect. The adjustment then used the same luminance matte to gradually apply the adjustments to the outer bounds of the frame. The specific values were chosen to allow clear detection of motion but not allow easy distinction of specific colors or forms, which is consistent with the capabilities of human peripheral vision.

Human Visual Field and Perception

The human eye is a biologically and physiologically complex organ. The back of the human eye is composed of the retina, which is a light-sensitive membrane [7]-[9]. Within the retina are photoreceptors, which are comprised of "rods" and "cones." Rods are photoreceptors (i.e., light-sensitive cells) that are highly sensitive to light and therefore assist with low light vision and excel at motion detection; however, rods lack color discernment. Cone cells process color and provide sharp, acute visual focus and are concentrated near the center of the human field of view.

The rear of the human eye contains an area referred to as the "macula." The macula is a small area at the back of the eye where light is focused and is responsible for our "central" vision [8]. Located within the macula is the "fovea," which is derived from the Greek word meaning "small pit." The fovea is a small depression within the macula. It is within the fovea that the majority of the retina's cone cells are concentrated. The human eye has significantly more rod cells than cone cells; however, it is within the fovea that cone cell density is at its highest. Another area that is often defined is the "perifovea," which is an area of the eye that extends from the foveal rim (i.e., the edge of the rod-free boundary of the center of the fovea) out to approximately 5° eccentricity.

As previously discussed, the human field of view is quite large, extending nearly 180° with both eyes open [5]-[6]. Each eye can see approximately 155° horizontally, 60° vertically up, and 75° vertically down [10]. While most humans are unaware, even with such a large field of view, only a very small portion of the human field of view is in sharp, acute focus and at its highest contrast. A general "rule of thumb" is that what is in sharp, clear focus is approximately the size of a thumbnail when the arm is extended to its full length.

Prior studies have determined that the fovea is only approximately 1° eccentricity. That is, only approximately 1° of the human field of view consists purely of cone cells and is where human visual resolution is at its highest. The perifovea extends only to approximately 5° eccentricity [5]-[6]. Beyond the perifovea — or beyond that approximately 5° central field of view — is defined as "peripheral vision." It is within the peripheral field of view that density of cone cells drops dramatically, with the vast majority of photoreceptors comprised of rod cells. In other words, beyond approximately 5° eccentricity of the human field of view, visual acuity drops dramatically, with objects becoming increasingly "blurred" or "out of focus" with increasing eccentricity (i.e., with increasing angular departure from central focus) [11].

Due to the limited central view of the reconstruction that is in focus, it often appears to an outside observer to be an inaccurate representation of what the average person sees. However, a simple experiment can be performed. If an individual focuses solely on one word of this paper and does not move their eyes from that one word, only one to two words beyond that word of focus can be clearly discerned. It is because of additional human physiology that this narrow field of view is overcome.

The human eye is not static. As we go about our daily lives, it is constantly scanning and is rarely ever stationary. The human eye naturally shifts to the item of concern or focus. Utilizing the previous example, as we read, our eyes move from word to word. The eye is typically not stationary as we read but instead moves across the pages. Likewise, as we drive our vehicles, our eyes constantly scan the road ahead, our speedometer, and the world around us. Therefore, it is not apparent that the sharp and clear focus area of our field of view is very narrow or limited. However, for the subject incident, the law enforcement officer was focused on the vehicle and its occupants as viewed through the rifle scope, thus limiting the likely range of eye movement and object focus.

As our field of view expands into our peripheral vision, objects become increasingly "blurred" or lack definition and clarity. Studies have shown that at approximately 40° eccentricity (or 40° from our central focus), the world is "90% blurred" [11]. One visual scientist from 1976 described peripheral vision as, "When I look at something it is as if a pointer extends from my eye to an object. The 'pointer' is my gaze, and what it touches I see most clearly. Things are less distinct as they lie farther from my gaze. It is not as if these things go out of focus — but rather it's as if they somehow lose the quality of form" [5]. It is this loss of "quality of form" that becomes critical when attempting to present or reconstruct what is viewed by an individual. Thus, the central question to be answered for the shooting trial necessitated, by its very nature, an understanding and representation of human field of view.

Utilizing the procedure and process described above, the authors were able to reconstruct the incident and place a virtual camera at the same position as the defendant's eye. It is at this point that the forensic engineering and reconstruction begins to end and collaboration with the professor of psychology increases and becomes more important. Prior to working with the professor, the authors utilized methods within their suite of software tools to represent the loss of visual acuity described in various medical journals and articles.

Figure 10
Still image from the reconstruction and visualization demonstrating a 130° field of view.

Figure 11
Still image from the reconstruction and visualization demonstrating a 40° field of view.

The Final Reconstruction

Following the process described above, and with the assistance, refinement, knowledge, experience, and expertise of the professor, the authors produced three final visualizations that aided with answering the question of what the responding officer "saw." The final visualizations included varying fields-of-view presented at 130° (**Figure 10**), 40° (**Figure 11**), and 20° (**Figure 12**). As discussed above, the human field of vision is very large. The 130° field of view was presented; however, due to the seemingly inaccurate representation of such a wide field of view on such a narrow medium (i.e., a computer screen or television screen), and due to the lack of the third dimension, this visualization was not presented at trial.

The 20° field of view was also provided based upon the very limited portion of the human field of view that is in sharp, clear contrast, as well as the fact that the defendant had one eye closed and was focused down the service rifle optic. However, like the 130° field of view reconstruction, this visualization was not presented at trial because most average individuals would claim they can "see more" than what is shown in the 20° reconstruction. While it is accurate to say the human field of view extends well beyond 20°, what is in sharp and clear focus is even less than would be shown in the 20° reconstruction. Therefore, the 40° field of view reconstruction was presented to the jury. As discussed above, a 40° field of view has been historically presented as being "typical" or "normal"

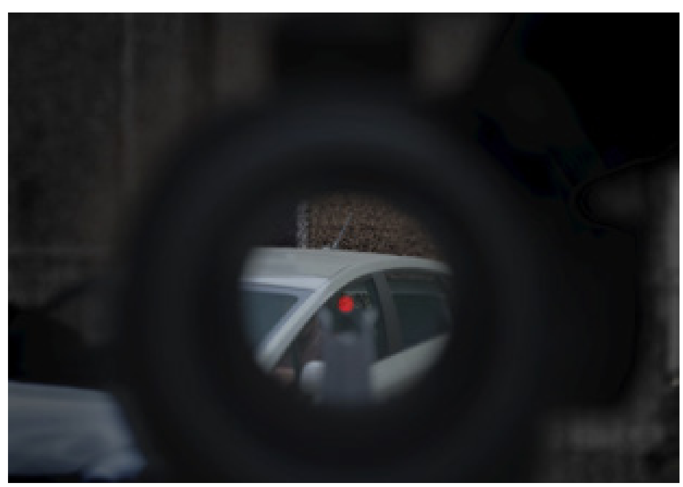

Figure 12
Still image from the authors' reconstruction and visualization demonstrating a 20° field of view.

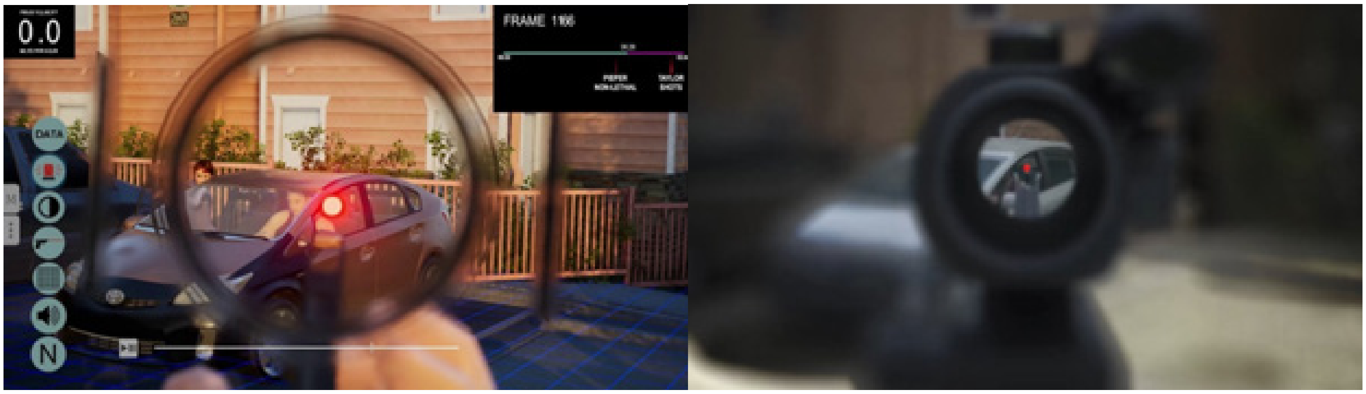

Figure 13
Side-by-side comparison of the prosecution's reconstruction (left) and the authors' reconstruction (right).

for human vision. Furthermore, a 40° field of view is the approximate field of view presented by the prosecution's reconstruction, thus allowing for a side-by-side comparison (**Figure 13**).

As can be seen from the still images of the reconstructions, the question of what the officer "saw" is not as simple as it may seem. Even with the reconstruction performed, the question of what the officer "saw" is still not easily answered, requiring the expertise of individuals such as the professor of psychology. And even while the professor can provide insight into human perception and cognition, it is impossible to know precisely what the officer "saw," "perceived," or "understood" at the exact moment the shots were fired. However, a thorough, accurate, meticulous reconstruction, with the help of highly specialized and trained experts, can help in working toward that answer.

Summary

Although the reconstruction performed by the prosecution's expert was an involved, labor-intensive, and scientifically accurate reconstruction of the positions of law enforcement officers, law enforcement vehicles, and the defendant, their reconstruction was misleading as presented to the jury about what the defendant "saw." The interactive reconstruction provided by the prosecution would have been valuable in evaluating the law enforcement agency's response with regard to positioning of officers, procedures, policies, and a review of the totality of the incident. However, their reconstruction was not a fair representation of the case being presented by the prosecution's claims of what the defendant "saw" or what he should have seen that informed his decision of whether to fire his service weapon or not.

The prosecution argued that the law enforcement officer should have been able to identify that the victim had turned the front wheels of his vehicle away from the officer and down a dead-end drive lane; therefore, the victim posed no threat to the responding law enforcement officers. However, as can be seen from the author's reconstruction, and with the aid of the professor of psychology, what was visible to the officer, and therefore what he "saw" or "perceived" was not accurately represented by the prosecution's reconstruction.

What a human "sees" involves specialized areas that extend beyond the expertise of a typical engineering reconstruction. Human perception and cognition are highly specialized fields that require the guidance and expertise of individuals trained and educated in psychology and human physiology. The reconstructionist must be aware of their limitations with regard to their expertise and technological representation of uniquely human functions such as vision, perception, and cognition. When the question is asked, "What did they see?" careful consideration must be given to ensuring what is presented is accurate and representative of what is possible within human anatomy and psychology. While interactive reconstructions can provide valuable information, such interactions must not be misconstrued as presenting something the interaction simply cannot scientifically support.

Conclusion

Forensic engineering incident reconstruction is invaluable in understanding, evaluating, and investigating an incident. The three-dimensional reconstruction can provide insight into the totality of an incident, thus allowing the investigator to apply rigorous forensic engineering investigation methodologies. However, it is crucial that the investigator understand their limitations, particularly as it relates to what the reconstruction shows, or what questions the reconstruction can answer. Furthermore, interactive reconstructions can provide an even broader analysis and view of an incident, allowing the incident to play out "in real time" and allow a frame-by-frame understanding of the incident. However, such reconstructions also have the immense capacity to be misleading and prejudicial.

A seemingly innocuous question, "What did someone see?" couldn't be further from innocuous. Human vision, cognition, and perception are immensely complex and complicated matters that extend far beyond the purview of a forensic engineering investigation. Such matters as what someone "sees" requires very esoteric experience, education, and training. Thus, it is imperative that the forensic engineer understand their knowledge and experience limitations. It is also imperative that the forensic engineer understand the limitations of their reconstruction, what their reconstruction is truly showing or representing to the triers of fact, and limit the conclusions and opinions that they can formulate and arrive at.

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