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Advanced Technologies Utilized in the Reconstruction of an Officer-Involved Shooting Incident

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Abstract

This paper presents a case study that utilized many of the latest forensic technologies to reconstruct the events that occurred during an officer-involved shooting incident in which a police officer fatally shot a fellow police officer. The shooting reconstruction utilized 3-D high-definition laser scanning, "matchmoving" of police helicopter infrared video footage, motion capture, photogrammetry, creation of a 3-D interactive virtual shooting scene, and virtual reality display systems. It also outlines how the trajectory of bullets were reconstructed, and how the position and posture of the shooting officer and victim officer were determined. Finally, federal judge rulings on various Daubert motions (509 U.S. 579 [1993]) to exclude or limit testimony of expert witnesses are presented.

Keywords

Police-involved shooting, bullet trajectory, 3-D laser scanning, matchmoving, motion capture, photogrammetry, forensic engineering, videogrammetry, virtual reality, Daubert

Introduction

An officer-involved shooting incident occurred at night, during a police investigation related to gunshots reported in a residential area. Officer Dole*, a 35-year-old male police officer, was looking over a privacy fence that separated two properties when he was shot by a fellow officer (Officer Baker*). Officer Baker fired six rounds at Officer Dole, striking him once in the head and killing him.

The fundamental questions posed to the authors were:

1. What was the order of the shots fired?

2. Which shot was the fatal shot?

3. What was Officer Dole's position and posture when Officer Baker shot him?

4. What was Officer Baker's view of Officer Dole when he shot him?

Procedure

To answer those questions, a reconstruction of the shooting incident was conducted by the authors who reviewed the physical evidence documented by the police at the shooting scene and used some of the latest forensic technologies to properly reconstruct key components of the shooting scene and perform an accurate virtual bullet trajectory analysis of the shots fired by Officer Baker.

The reconstruction included an inspection of the shooting site that involved using high-definition laser scanning technology[++] to capture and document the area and all available evidence. The highly accurate, 3-D data collected in the form of a point cloud was used to create an interactive, 3-D virtual model of the shooting scene. This virtual shooting scene model was used to perform bullet trajectory analysis and determine:

(a) The position and posture of Officer Dole,

(b) Officer Baker's position, and

* Officers' names used are fictional.

[++] The authors used a Faro Focus 3D laser scanner (www.faro.com).

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(c) What Officer Baker could likely have seen at the time of the fatal shooting.

The point cloud also enabled the authors to use photogrammetry on police photos to accurately document and reconstruct evidence that had been removed from the scene. The point cloud was also used with a videogrammetric process called "matchmoving" that was performed on provided police helicopter video footage, which showed the position and posture of Officer Dole for a period of time prior to the shooting.

The matchmoving process was used to solve for the properties and 3-D path of the moving police helicopter camera relative to the point cloud of the shooting site. The photogrammetry and videogrammetry, combined with the virtual bullet trajectory analysis, allowed the authors to determine the probable location and posture of Officer Dole along the fence as well as where Officer Baker was and what he could likely see at the time of the shooting.

Finally, the primary author's analysis and opinions passed all Daubert‡ challenges by the defense, while the testimony of some other experts was limited by the judge.

Background

At approximately 2 a.m., the police department was called to a home in a residential area (labeled in red in **Figure 1**) on the report of shots fired. Police officers from other metro jurisdictions also responded to the call. A total of 29 police officers and a police department helicopter with Forward Looking Infrared Radar (FLIR) video responded.

One of the responding officers witnessed a person step out of an exterior door on the north side of the residence

Figure 1
Aerial view of the residence.

Figure 2
Aerial map of shooting area.

into the carport area (see black dot labeled with a red X in **Figure 2**) of the single-story residence, fire a gun, and return inside.

Police determined that the residence had three occupants who were contacted by police and ordered to vacate the residence through the front door — which they did. At around that time, Officer Dole and another officer positioned themselves in the area to the north of a wooden privacy fence that bordered the north side of the residence (see **Figure 2**). Both officers could look over the fence by standing on an aluminum extension ladder that was on the ground horizontally and leaning against a chain-link fence immediately north of the wooden privacy fence (**Figure 3**).

Other officers had moved to the front door of the residence and requested additional officers to assist in clearing the house. The officer who was with Officer Dole, north

Figure 3
Extension ladder on the north side of the wooden privacy fence, bordering the residence.

‡ A Daubert challenge is a hearing before the judge where opposing counsel challenges the admissibility of expert testimony.

Figure 4
Panoramic image of carport area "stitched" together from four police investigation photos.

of the privacy fence, left his position and joined the other officers who entered the house and cleared the front rooms of the house.

Officer Baker, who was responding to the call for assistance, arrived on the scene at around 3:15 a.m. and joined the officers who were clearing the house. A decision to visually clear the remaining rooms from the outside was made; Officer Baker and two other officers dressed in full SWAT gear and armed with rifles exited the north side of the house through a door that led to the carport area and into the backyard, which had not yet been cleared (**Figure 4**).

Based on Officer Baker's testimony, upon exiting the house, Officer Baker went immediately to the left, took a few steps toward the west, and cleared the area to his left. Then Officer Baker moved out toward the north (to the left of the northwest carport post) and began to visually scan from his left to his right. As Officer Baker "pied"[±] around the post with his Bushmaster AR15 rifle, he reportedly heard a voice from the area of the privacy fence to the north say: "Hey."

Officer Baker activated his rifle-mounted light and scanned to his right and made visual contact with the person. Officer Baker could see the person's left hand, head, and right hand up over the top of the fence. Officer Baker testified that he saw a black semi-automatic handgun in the person's right hand and yelled, "Police, drop the gun, drop the gun." Officer Baker then fired six rifle rounds at the person on the fence. The person fell back away from the fence, and Officer Baker stopped shooting. The shots were fired at around 3:48 a.m.

Later, the person that was down was identified as Officer Dole. His body was found positioned on his back on the north side of the privacy fence with his head toward the apartment building with his feet still in contact with the ladder on which he had been standing. A paramedic was brought onto the scene and pronounced Officer Dole deceased. Officer Dole had a gunshot wound just below his left eye with an exit wound on the back, lower left side of his head (**Figure 5**).

Officer Dole's handgun and flashlight were found on the south side of the privacy fence. The magazine from the handgun was not inside the gun but was found along with one live round from the magazine near the handgun and flashlight (**Figure 6**).

Site Inspection

In conducting the shooting reconstruction, the authors performed an inspection of the site to collect information

Figure 5
Officer Dole's final resting position.

Figure 6
Police photo of Officer Dole's Glock 17 (Gen 4) handgun (#14), gun magazine (#15), one live 9-mm round (#16), and flashlight (#17) found on the south side of the privacy fence.

[±] "Pie-slicing" or "slicing the pie" is a tactical technique that allows the slow, gradual observation around a corner or other obstacle.

Figure 7
Point cloud of the shooting site captured by the authors with a Faro Focus 3D high-definition laser scanner.

pertinent to the investigation. The inspection, one year after the shooting incident, consisted of measuring, photographing, and using high-definition laser scanning technology to scan the shooting site to document the available physical evidence, obtain accurate measurements (for the purpose of bullet trajectory analysis), and reconstruct the shooting. The highly accurate (within a few millimeters) data was collected by a Faro Focus 3-D scanner and consisted of more than 400 million 3-D data points, collectively called a "point cloud," as shown in **Figure 7**.

Evidence Documentation

During the site inspection, the authors photographed, measured, and scanned five bullet marks, which were visible on the southern exterior wall of the neighboring two-story apartment building. The five marks present were consistent with marks documented during the police investigation (**Figure 8**). The police had documented two other marks on a portion of a downspout that had since been removed and was not available during the inspection.

In addition to the marks on the brick wall, the authors also photographed, measured, and scanned a single hole in the wooden privacy fence and a scuff mark on the concrete footing below the fence, possibly left by Officer Dole's handgun as it was released and fell to the ground (**Figure 9**).

By using high-definition laser scanning technology in their inspection, the authors were able to capture a vast point cloud that documented the entire shooting scene, including all available evidence marks. The level of detail and degree of accuracy of the point cloud allowed the authors to apply various accepted scientific methods (photogrammetry, videogrammetry, and bullet trajectory analysis) to the data with a very high degree of engineering certainty.

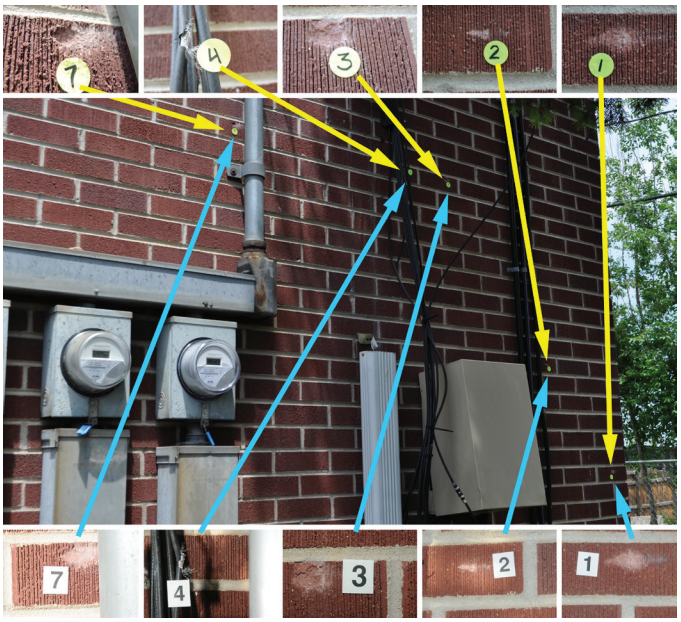

Figure 8
Marks on southern wall of apartment building left by bullets (middle); the authors' inspection photos (top); and police photos (bottom).

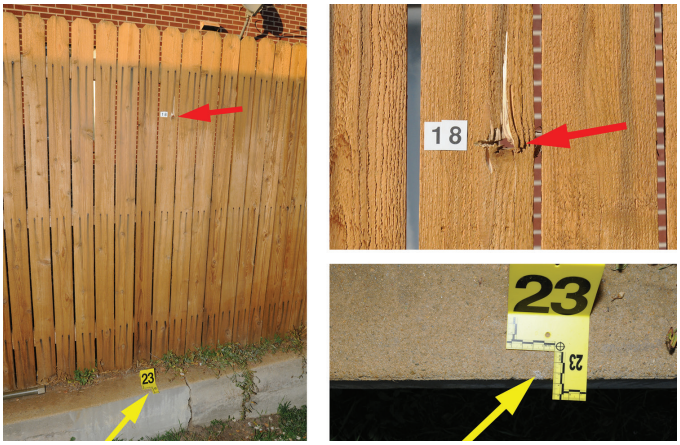

Figure 9
Single bullet hole in wooden privacy fence picket (red arrow); scuff mark on concrete footing (yellow arrow).

Photogrammetry Analysis

As part of the reconstruction, the authors performed photogrammetry on police photographs in order to properly reconstruct key components of the shooting scene, including the carport, the tarp that was hanging on the north side of the carport (which had been removed prior to the authors' inspection), the position of the vehicle under the carport (**Figure 10**), the resting position of Officer Dole's body (**Figure 11**), his handgun, the magazine from his handgun, the live round from the magazine, and his flashlight.

Video Analysis

The authors also performed videogrammetry on provided video footage captured by the police department helicopter's FLIR camera, which detects heat. In the video, Officer Dole was seen standing in an upright position on the aluminum extension ladder as the helicopter circled the shooting scene. Using data from the point cloud of the

Figure 10
Photogrammetry performed to determine where the carport and hanging tarp were during the time of the shooting.

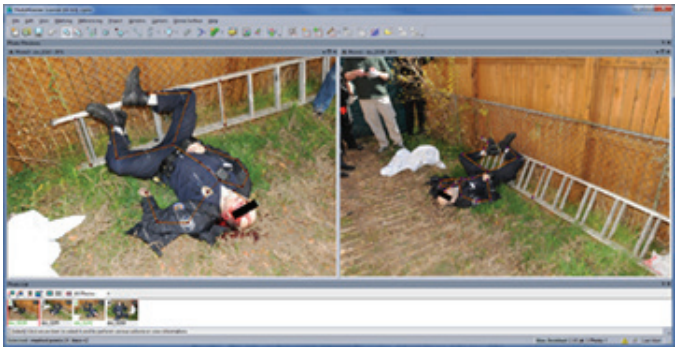

Figure 11
Photogrammetry performed on police shooting scene photos of Officer Dole's final resting position after being shot.

shooting site, a scientific process called "matchmoving" (also called "camera tracking") was used to define a virtual camera that "matches" the location, orientation, focal length, and lens distortion of the camera used to record the provided video footage.

Using specialized software (SynthEyes by Andersson Technologies), 2-D points ("features") were identified and tracked through multiple frames of the video. Each feature represented a specific point on the surface of some fixed object in the shooting scene (i.e., fence posts, roof corners, vents, windows, etc.). Each tracked feature was then assigned and constrained to the feature's corresponding 3-D coordinates (x, y, z) as defined by the shooting scene point cloud. The software then mathematically solved for ("calibrated") a virtual camera (within the virtual shooting scene), which emulated the real-world camera that was used to record the video footage.

While viewing the 3-D shooting scene through the lens of the solved virtual camera, a computer-generated, 3-D character model of Officer Dole was inserted into the scene to accurately mark the position of Officer Dole along the fence as seen in the video (**Figure 12**).

Virtual Interactive Shooting Scene

The authors created a highly detailed and accurate 3-D computer model of the shooting scene based on the point cloud captured during the authors' inspection of the shooting site. The computer model, along with data attained through the photogrammetry and videogrammetry, was combined into an interactive virtual environment, which is shown in **Figure 13**. The interactive virtual environment allowed the authors to move around and view the virtual shooting scene from any vantage point, perform bullet trajectory analysis, test/analyze the position/pose of Officer Dole on the fence, and test/analyze the position of

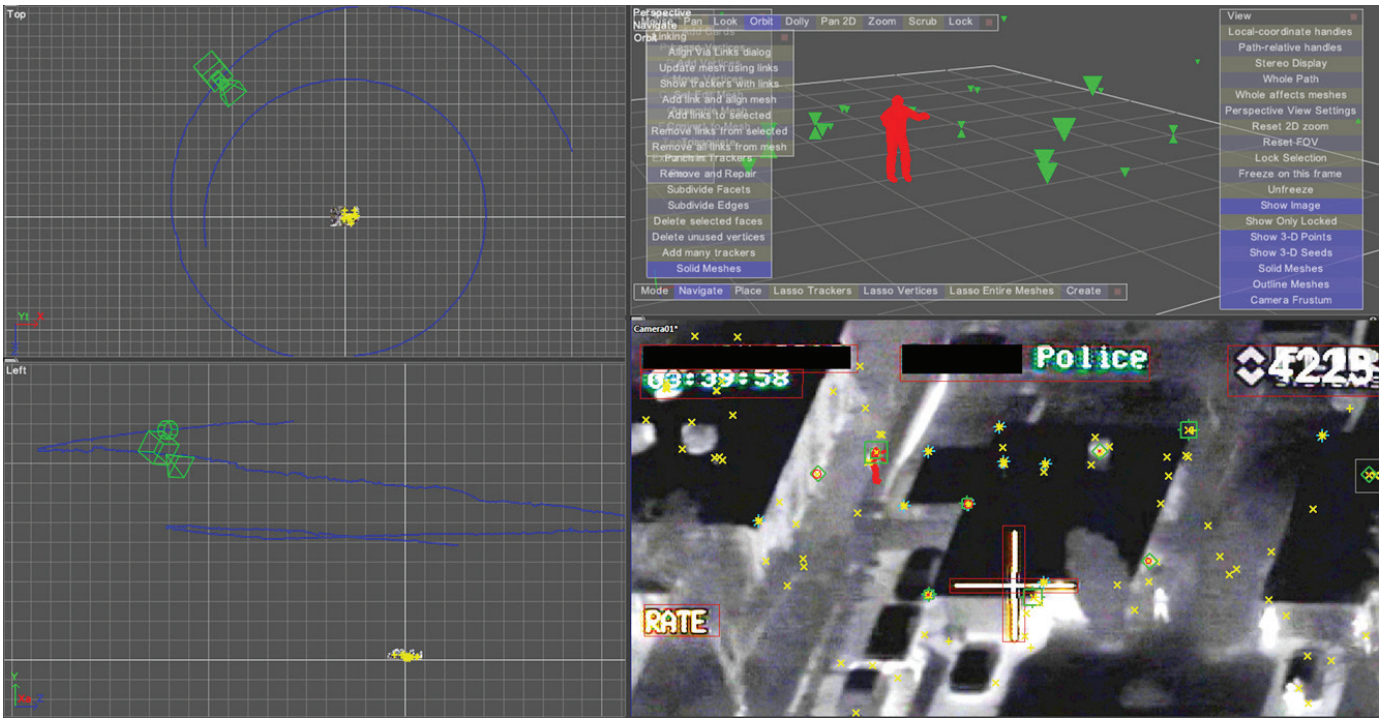

Figure 12
Camera match of provided police helicopter video footage.

Figure 13
Interactive 3-D virtual shooting scene based on point cloud from HD Laser Scanning (shown on the right).

Officer Baker during the shooting.

Bullet Trajectory Analysis

According to the police investigation of the shooting scene, six .223 (5.56-mm) caliber spent casings from Officer Baker's rifle were found in the carport area near the north-facing exterior door and the rear of the parked vehicle. The general location of the six casings was consistent with an AR15's right-facing ejection port and the area where Officer Baker was reported to be when he fired his rifle at Officer Dole.

The virtual model of the shooting scene included accurate locations of all the evidence items on the southern exterior wall of the apartment building documented by the authors, as well as the precise location of the bullet hole in the wooden privacy fence (#18) and scuff mark left by the falling handgun on the concrete footing (#23). A digital model of the portion of downspout, which was missing at the time of the inspection, was added to the virtual shooting scene model, and evidence marks #5 and #6 were located using photogrammetry techniques on police scene photos.

The virtual shooting scene model allowed the authors to perform an accurate bullet trajectory analysis by connecting evidence items on the brick wall and evidence item #18 (the bullet hole in the privacy fence) back to a point representing the end of Officer Baker's rifle, approximately 62.5 inches off the ground at the location where Officer Baker was determined to be standing at the time of the shooting (**Figure 14**). This height was estimated by police in their initial investigation using a trajectory rod and string. The authors also confirmed this by posing a virtual surrogate model in the same shooting stance Officer Baker demonstrated during a video-recorded deposition.

The authors utilized the virtual shooting scene to analyze the evidence, and made the following findings. Note

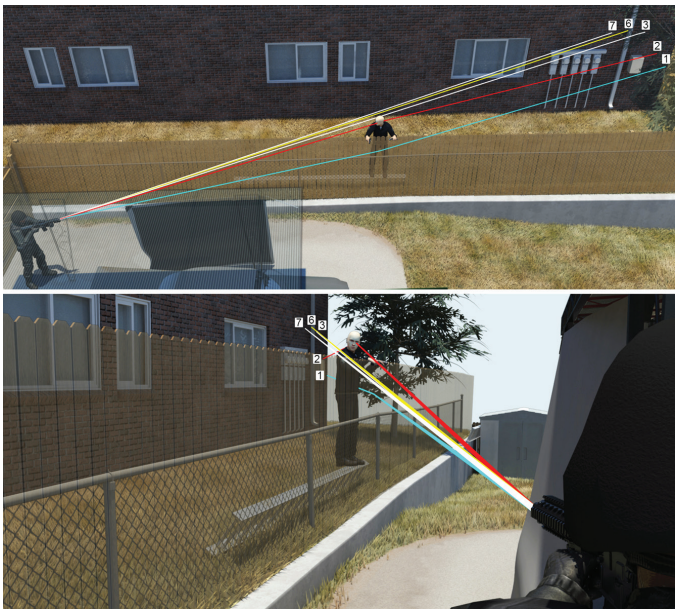

Figure 14
Bullet trajectory analysis performed in interactive virtual shooting scene.

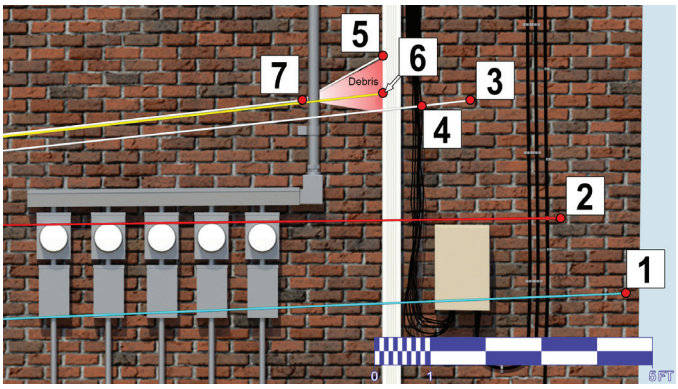

Figure 15
Evidence matched to bullet trajectories.

that all described bullet marks were confirmed as being made by bullets by the police crime laboratory, but DNA test results of the marks (if any were obtained) were not revealed in discovery.

Evidence Item (see **Figure 15**):

- #1 – Mark on brick wall made from a bullet. This mark on the wall was below the elevation of the top of the privacy fence and the lowest mark left on the wall.

- #2 – Mark on brick wall made from a bullet. Before hitting the wall, the bullet clipped and left a gouge mark on a vertical cable fixed to the wall. These two marks (gouge mark on cable and mark on wall) were at the same elevation (**Figure 16**), indicating a relatively level trajectory for the bullet that made these two marks.

Figure 16
The gouge mark on the vertical cable and the mark on the wall at evidence item #2 are at the same elevation, indicating a relatively horizontal trajectory for the bullet that made these two marks.

- #3 and #4 – A bullet made a mark on a vertical cable (#4) and then left a mark on the wall (#3).

- #5 – Mark on downspout made from ricocheted bullet after hitting the wall and leaving a mark at evidence item #7.

- #6 – A group of holes and marks in the downspout. Some of the holes and damage are made from debris from the bullet contact at evidence item #7. One to two of the holes may have been made by one or two of the shots fired (not the bullet that created the debris).

- #7 – Mark on wall made from a bullet, which then ricocheted, leaving evidence item #5 on downspout.

- #18 – Bullet hole in fence.

- #23 – Scuff mark on the concrete footing below the fence created by Officer Dole's handgun as it fell to the ground on the south side of the fence.

Based on the authors' bullet trajectory analysis, Officer Baker's height, a normal shooting stance, and the angle of the bullet penetration through the fence, the authors confirmed that the shot fired through the fence was done from a rifle muzzle at a height of approximately

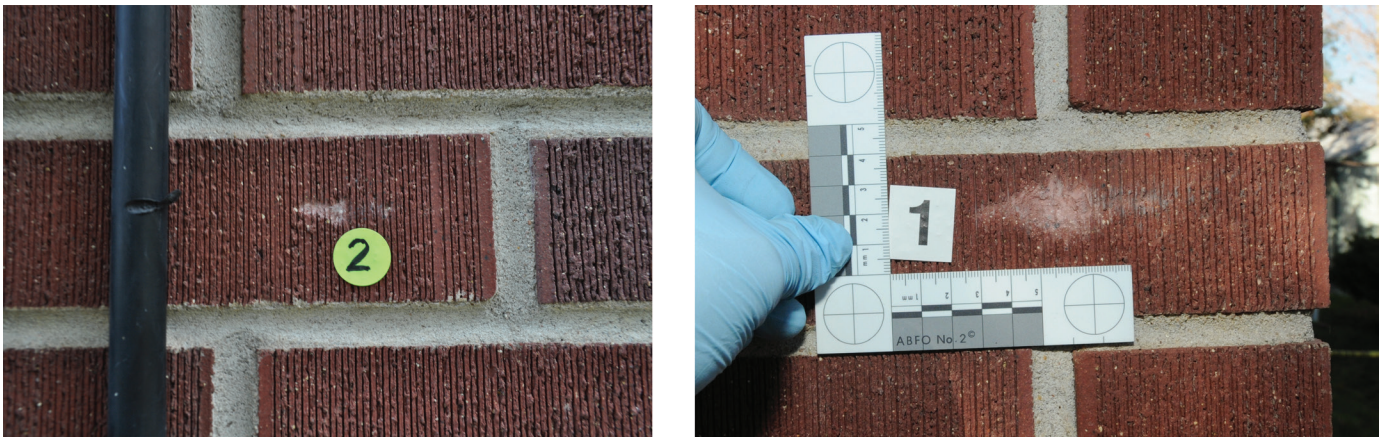

Figure 17
Horizontal bullet mark left at evidence item #1 and relatively horizontal mark left at evidence item #2.

62.5 inches above the ground, which agreed with the police investigation.

The authors also determined that the bullets that left marks for evidence items #3, #4, #5, #6, and #7 were shot above the fence from Officer Baker's shooting position. Furthermore, one of the two bullets that left the marks for evidence items #1 and #2 on the wall passed through the privacy fence, and the other bullet passed through Officer Dole's head. Both of these bullets were deflected as they passed through Dole's head and the fence, respectively.

The marks at evidence items #1 and #2 are both relatively horizontal marks on the wall (**Figure 17**), indicating that the bullets that left those marks had relatively level trajectories, which can be true of destabilized, deformed, and even tumbling, exiting bullets over short distances[1].

As mentioned, evidence item #2 was made after the bullet clipped and left a mark on a vertical cable at the same height as the mark on the wall. The height of evidence item #2 is consistent with a trajectory above the fence, while the height of evidence item #1 is consistent with a trajectory through the fence. Therefore, the authors determined that the bullet that passed through the fence (#18) left evidence item #1, and the fatal bullet that passed through Officer Dole's head clipped the vertical cable and left evidence item #2.

The authors were able to account for the four bullets that corresponded with evidence items: #1, #18, #2, #3, #4, #5 and #7. However, the authors were not able to positively account for the remaining two bullets (out of six) that were fired. Either both missed the apartment building wall, one of them missed the wall and the other hit the downspout (at evidence mark #6), or both hit the downspout.

Shot Timing Analysis

During an interview with an investigating detective, Officer Baker stated:

"*Um, so I fired uh, I had been holding the uh, my site, my optic, my rifle on the person's uh, head. When I saw the gun come up, urn, I thought I was gonna get shot. I fired my first round urn, at the person's head, urn, and then as I was — as soon as I fired that first round, uh, I think I began kind of retreating backwards, urn, just to try to get some distance and some kind of cover, and as I was doing that I transitioned down to the person's torso which uh, would've been just on the other side of the fence, just, you know, lowered my, my point of aim just a few inches. Urn, I fired I believe, four additional rounds. Urn, and as the person you know, fell back away from the fence, urn, I couldn't see him anymore. I at that point, he threw the gun away so I stopped firing.*"

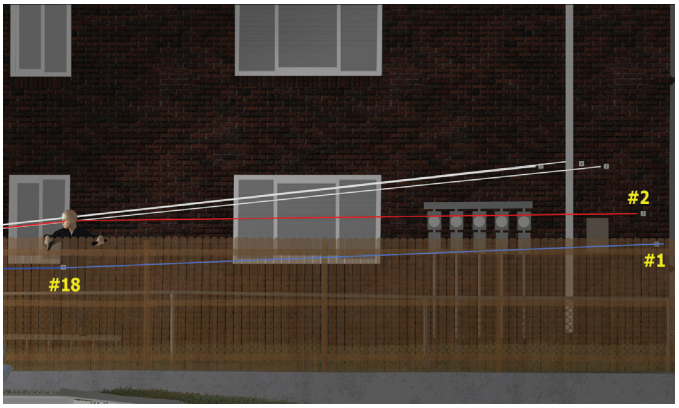

Figure 18
The authors' bullet trajectory analysis determined the bullet (red), which left mark #2 on the wall, was the bullet that passed through Agent Dole's head, and the bullet that left mark #1 was the bullet that passed through the fence (blue).

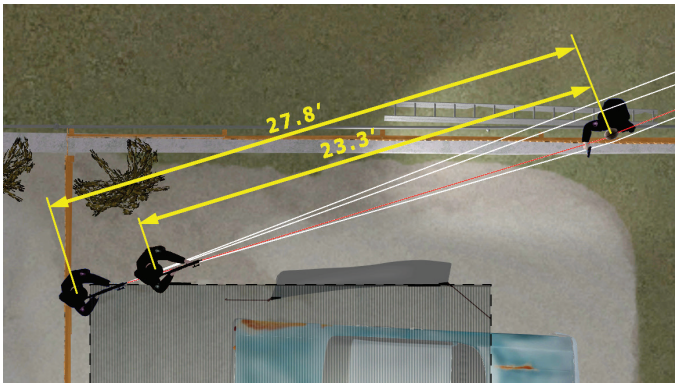

Figure 19
Range of positions Officer Baker was while firing the shots, as determined by the authors.

Figure 20
Still frame from police department helicopter FLIR video footage, showing Officer Dole standing upright, positioned with his right arm on the wooden privacy fence prior to the shooting. Zoomed view by the authors.

Considering the physical evidence, bullet trajectory analysis, and the statements made by Officer Baker, the authors determined that:

- Officer Baker fired a total of six shots.
- The first shot fired was the fatal shot (this was the consensus of all involved experts) and left mark evidence item #2 on the apartment building wall, as shown in **Figure 18**.
- One of the five remaining bullets passed through the fence (evidence item #18) and left mark evidence item #1 on the apartment building wall.
- All remaining four bullets were shot above the fence line.

The Shooter's Position and Motion Analysis

Considering the available evidence, the authors used the virtual shooting scene and bullet trajectory analysis to determine the range of positions Officer Baker could have been while firing the shots. The authors determined the nearest and furthest distance Officer Baker was from Officer Dole (while shooting) to be 23.3 feet and 27.8 feet, respectively (**Figure 19**). The nearest distance was determined by moving Officer Baker in the virtual scene as close to Officer Dole without the bullet trajectories of the bullets, which left evident marks #3-#7 on the brick wall, hitting the fence. The farthest distance was determined by moving the virtual Officer Baker back until he was restricted by the fence behind him (**Figure 19**).

Shot Officer's Position/Posture/Pose Analysis

To reconstruct the horizontal position where Officer Dole was along the fence, moments before Officer Baker shot him, the authors used photogrammetry performed on provided police photos of Officer Dole's body, lying on the ground, after he was shot to determine where his feet were on the ladder and where the ladder was in respect to the privacy fence. Additionally, the authors used the scuff mark on the concrete footing, likely left by Officer Dole's handgun, to place Officer Dole's right hand on the fence.

To reconstruct Officer Dole's posture, the authors first used the video analysis of the provided police department's helicopter video footage, which showed that Officer Dole was standing straight up, maintaining his position on the ladder for the entire time he can be seen by the camera, which was a total of approximately half of the 20-minute video. Officer Dole is intermittently occluded by the two-story apartment building as the police helicopter is circling the scene. Furthermore, when the video camera zooms in, at various times throughout the video, Officer Dole can clearly be seen standing with his left and/or right hand on top or over the fence, as shown in **Figure 20**.

Secondly, the authors matched the exit wound on the back of Officer Dole's head with the trajectory of the fatal bullet that left the gouge mark on the vertical cable and then left evidence mark #2 on the brick wall.

Thirdly, in conducting analysis and assessment of Officer Dole's position, posture, and pose at the time of the shooting, the authors placed, within the virtual shooting scene, a virtual character model of the same height and body type as Officer Dole, on top of the ladder in

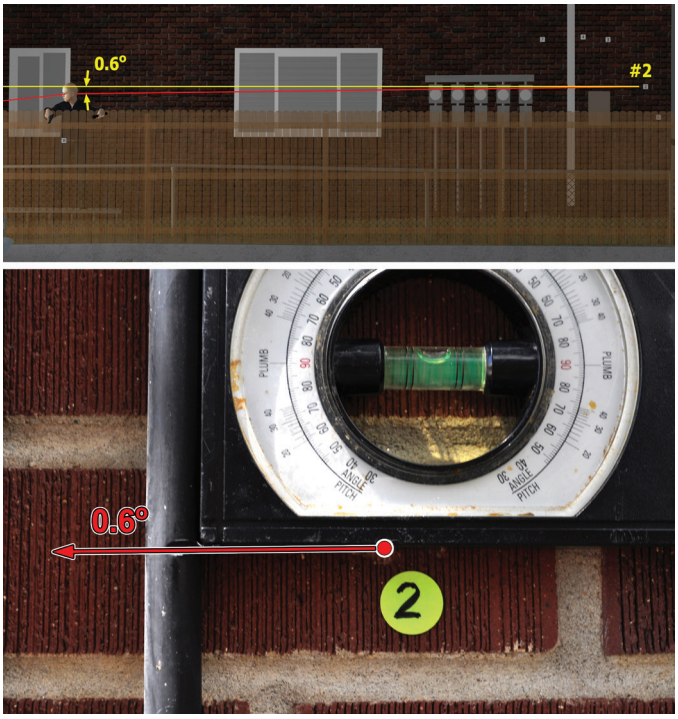

Figure 21
The trajectory of a bullet leaving the back of Officer Dole's head from an elevation defined by the authors' shooting reconstruction and leaving a mark at evidence item #2 was consistent with the physical evidence.

the lateral position along the fence (determined through photogrammetry and videogrammetry) as discussed previously. The authors posed the virtual character to be standing up and then connected the exit wound on the back of Officer Dole's head to the bullet mark at evidence item #2 on the wall. The trajectory line passes through the gouge mark on the vertical cable and is consistent with a relatively level trajectory indicated by the horizontal mark of the fatal bullet, as shown in **Figure 21**.

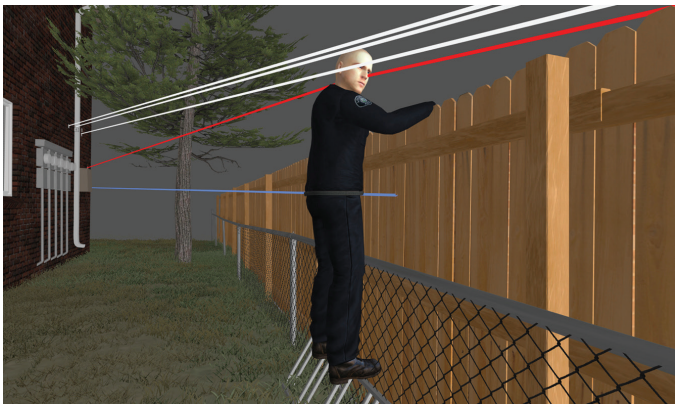

Figure 22
Probable position, posture, and pose of Officer Dole as determined by the authors. View from the north side of the wooden fence.

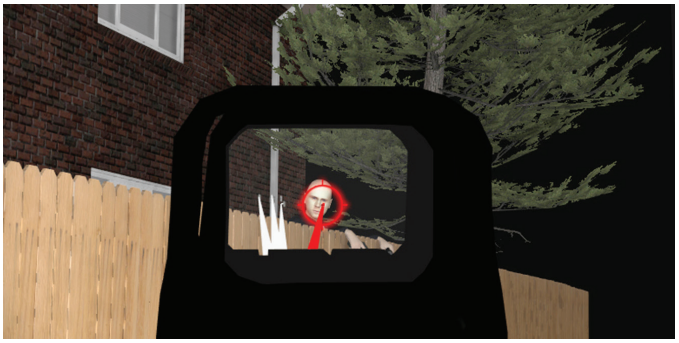

Figure 23
View from Officer Baker's point of view of Officer Dole at the time of the shooting, as determined by the authors.

The elevation of Officer Dole's head in the position/posture/pose determined by the authors (**Figure 22**) is consistent with the physical evidence, which indicates a relatively level trajectory of the fatal bullet exiting Officer Dole's head, clipping the cable and leaving the mark at evidence item #2, as previously discussed and shown in **Figure 18**.

Once the reconstruction was completed, the authors were able to determine what Officer Baker should have been able to see from his point of view when he first saw Officer Dole and then fired six times, fatally striking Officer Dole in the head (**Figure 23**).

Daubert Challenges

While the defense agreed with some of the authors' conclusions regarding the shooting, they claimed that the authors' expert report conveyed a false level of precision with regard to their analysis based on the use of various technologies, specifically high-definition laser scanning.

The defense also argued that in concluding Officer Dole's head location was above the fence, the authors did not determine or take into account the amount of deflection of the bullet as it passed through Officer Dole's head, and that the authors were solely basing their conclusion on "extrapolating" a bullet path angle from the alignment of bullet strike mark #2 on the brick wall to the gouge on the adjacent cable. The defense argued that such a calculation would have limited precision because the amount of deflection from passing though Officer Dole's head was unknown, and the angle of the bullet path afterward cannot be determined to a high level of precision.

As discussed above, the deflection of the bullet as it traveled through Officer Dole's head is irrelevant in determining the path the bullet took upon exiting Officer Dole's head. All that is required in determining the path of

the bullet in 3-D space is three points, working backward: 1) mark on the brick wall; 2) gouge in vertical cable; and 3) exit wound on the back of Officer Dole's head. The defense also claimed that the author's analysis of video footage taken 40 minutes prior to the shooting was irrelevant to Officer Dole's position at the time of the shooting.

The judge ruled:

"The judge denied [the defendant's] motion to exclude or limit expert testimony of Dr. Richard Ziernicki. The judge found that helicopter video of [Officer Dole] standing in an upright position on a ladder and remaining in the same location and position throughout the video footage was one objective physical fact that was used to test and confirm Ziernicki's opinion that [Officer Dole] was probably standing upright on the ladder when he was shot."

"[Officer Dole's] positioning and movements, including where and how he was holding his weapon, immediately before he was shot are important facts in this case. Apparently, the shooter is the only available eyewitness to these facts. But one must bear in mind that by connecting the marks on the wall and adjacent cable, and the exit wound, he [Ziernicki] can determine where [Officer Dole's] head was when the shot was fired. One can agree or disagree with his opinion, the judge said[2]."

Virtual Reality Technology

By utilizing an Oculus Rift[3] virtual reality headset (shown in **Figure 24**), the authors were able to interactively navigate and experience the virtual shooting scene from an immersive, first-person point of view as shown in **Figure 25**. This technology creates stereoscopic 3-D views, which provided the authors a powerful tool to accurately simulate and test a range of possible positions/poses that Officer Dole was in as well as the range of locations Officer Baker was shooting from.

Figure 24
Oculus Rift Virtual Reality headset used to view the interactive virtual shooting scene.

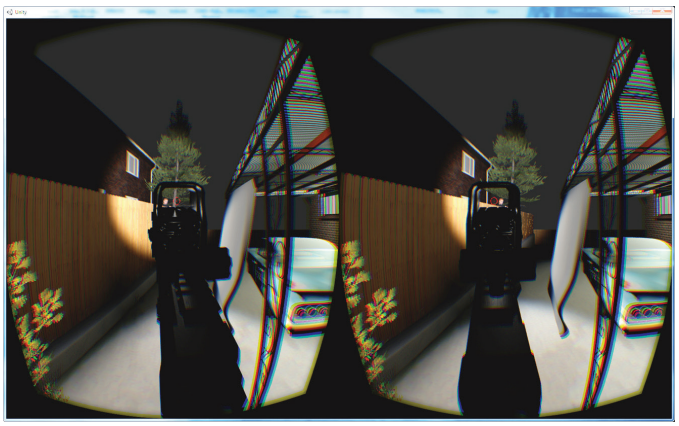

Figure 25
Immersive (stereoscopic) first-person shooter point of view in the interactive, virtual shooting scene developed by the authors.

Conclusions

After the investigation was completed, the authors were able to answer questions regarding the order of shots, which shot was fatal, the position and posture of Officer Dole, and more.

This case study demonstrates the application of some of the latest technologies and methodologies used during the reconstruction of an officer-involved shooting incident. Such technologies, when used properly, can be effective for accurately reconstructing bullet trajectories and for analyzing surveillance video footage. Finally, these technologies and their use in shooting reconstruction (for this case) were validated and held up against Daubert challenges in court.

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