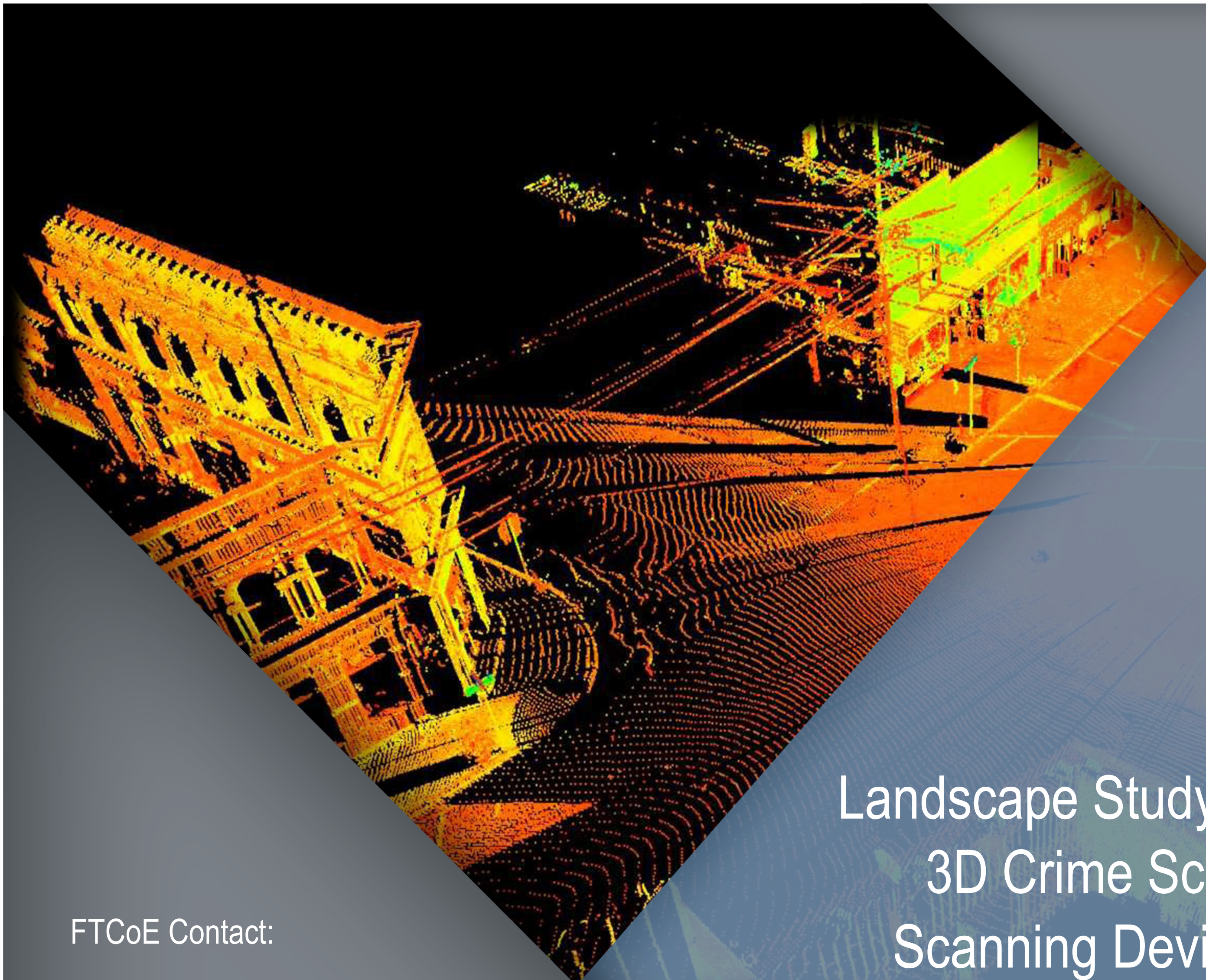

Landscape Study on 3D Crime Scene Scanning Devices (with 2018 Update)

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Information provided herein is intended to be objective and is based on data collected during primary and secondary research efforts available at the time this report was written. Any perceived value judgments may be based on the merits of device features and developer services as they apply to and benefit the law enforcement and forensic communities. The information provided herein is intended to provide a snapshot of current 3D scanning devices and a high-level summary of available devices; it is not intended as an exhaustive product summary. Features or capabilities of additional instruments or developers identified outside of this landscape may be compared with these instrument features and service offerings to aid in the information-gathering or decision-making processes. Experts, stakeholders, and practitioners offered insight related to the use of 3D scanners for law enforcement agencies.

Please note: while this report is intended to serve as a cross-section of available 3D scanners, the FTCoE strives to bring users the most complete picture of the market. If your company manufacturers a device that should be included in this report update, please reach out to the FTCoE.

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Updated Report Overview

This report, including a March 2018 update, was commissioned to highlight for the forensic community technology advances and new products related to 3D scanners for crime scenes. Since publishing the original report in January 2016, many of the featured manufacturers have launched new and improved 3D scanners. These products offer significant advancements in user-friendliness, performance, and functionality. This update augments the original landscape study with new user impact stories, an overview of the technology advances in the 3D scanning field, and information on new scanners on the market. The complete report continues to serve as a resource for crime laboratory directors, practitioners, and stakeholders within the forensic community for surveying commercially available 3D scanning instruments, understanding best practices for using 3D scanners, and making purchasing decisions. We recommend that readers consider the update, but also use the original report as a basis for deeper understanding of 3D laser scanning instruments, their benefits and limitations, procurement considerations, training, fielding, and use.

The National Institute of Justice's (NIJ's) Forensic Technology Center of Excellence (FTCoE) would like to thank the industry and forensic professionals who helped create this addendum to the original report:

- **Tony Grissim**—Major Account Manager, Leica Geosystems, Inc.; Monterey, CA
- **Will Henningsen**—Acting Manager, Omaha Police Department; Omaha, NE
- **Christopher Kercheval**—Technical Sales and Support Engineer, Z+F; Canonsburg, PA
- **Ed Phillips**—Accident Reconstruction Specialist, San Diego Co. Dept. of Public Works Traffic Engineering; San Diego, CA
- **Michael Russ**—Sheriff's Crime Scene Specialist III, Scientific Investigations Division, San Bernardino Sheriff's Department; San Bernardino, CA
- **Shannon Trammell**—TLS Business Development Manager/Forensic LiDAR Specialist, RIEGL Laser Measurement Systems; Orlando, FL
- **Janice White**—Director of Public Safety Product Management, FARO Technologies, Inc.; Portland, OR
- **Troy Wilson**—Crime Scene Unit Team Leader, Texas Ranger; Floresville, TX

Impact of 3D Scanning Devices in Law Enforcement

3D scanning devices, which provide thorough records of scenarios, such as crime scenes and vehicle accident scenes, continue to provide significant value to law enforcement in the criminal justice system. Agencies are adopting these technologies into their protocols for situations such as vehicle accidents and officer-involved shootings. Scans taken by these devices are now playing roles in successful court cases. Four new case studies illustrate the ways in which 3D scanning has positively impacted law enforcement agencies around the country.

Case studies include:

- **Success in prosecution**: Will Henningsen, Omaha Police Department (Page 3)
  Prosecutors used 3D scanners to corroborate testimony and evidence related to a crime scene rather than as standalone pieces of evidence and could identify the fatal shot via trajectory analysis.
- **Multi-agency collaboration and communication**: Michael Russ, San Bernardino Sheriff's Department (Page 4)
  3D scanners enabled departments to work together and share valuable information to stakeholders during the investigation of the 2015 San Bernardino terror attack.
- **Valuable scene perspective for juries**: Troy Wilson, Texas Ranger Crime Scene Unit (Page 5)
  3D scanners showed the spatial relationships to a jury in a case where a mother had shot her daughter, and was used during the investigation of the First Baptist Church shooting in Southerland Springs.
- **Faster scene processing with an upgraded device**: Ed Phillips, San Diego County Dept. of Public Works (Page 6)
  Time savings at the crime scene and while processing and rendering the scan cleared the scene sooner and permanently preserved evidence.

Case Study: 3D Scanning Evidence and Analysis Results in Successful Prosecution for the Omaha Police Department.

Will Henningsen is the Acting Manager of the Omaha Police Department and the Forensic Investigations Director of the International Association of Forensic & Security Metrology.

The Omaha Police Department deploys multiple 3D Leica scanners for collecting and capturing visual evidence at crime scenes. The department has used 3D scanners at more than 400 crime scenes and has written policies that require their use for homicides, shootings, and felonious assaults. The agency uses a sophisticated management system to manage the use of 3D scanners. They follow a formal process to create relevant renderings, perform advanced laboratory analyses, train investigators, and prepare evidence for court. Leica's supporting software package aids angular measurements for bullet reconstruction, modeling witness perspectives, and introducing external images for height approximation.

Gang violence erupted in the Clifton Hills neighborhood of Omaha, Nebraska on January 15, 2014.[1,2] Approximately 20 shots were fired. Payton Bensen, a 5-year-old girl eating breakfast, was struck and killed in her home. A blurry surveillance camera caught three suspects fleeing, leaving multiple bullet casings littered in the street. Upon their arrest, police confiscated a handgun and a high-powered rifle. The girl's family demanded justice, and the prosecution needed to determine whose bullet was ultimately responsible for the death. The 3D scanner identified defect entry and defect exit holes in a room and then calculated the deflection point to confirm that this bullet struck the girl. Further trajectory analysis and bullet casings matched the fatal blow to a specific firearm, the rifle, suggesting that Vincent Hicks had fired the fatal round. Hicks was convicted of second-degree murder and sentenced to 65 years in prison. Corroborating the 3D scanner evidence with eye witness testimony facilitated the **successful prosecution** of the case; without this technology, this outcome would have been unlikely.

Omaha police investigating bullet entry holes and trajectory paths. Photo credit: *Omaha World-Herald* staff.

The 3D scanner is most commonly used as a **unifying tool** for relating evidence to the scene and as a testifying tool. Creating precise diagrams and simulations of events help to construct the scene and relate key evidence to the chain of events, allowing officers to explain to juries using concrete images. The successful implementation of 3D scanners often requires substantial preparation of evidence. Since 3D scanners are very useful for relating testimony to evidence, they help with courtroom process and final adjudication.

> "While creating compelling visuals for court, 3D scanners provided value by leading to more plea bargains and stipulations, which reduce courtroom backlog."
>
> Will Henningsen, Omaha Police Dept.

Impact:

- 3D scanning devices **enable collecting objective and comprehensive evidence, significantly eliminating** errors induced by human choices and reducing practices that can disturb and contaminate evidence.
- **3D scanners typically augment testimony and other evidence** related to a crime scene. 3D scanners usually are not standalone pieces of evidence.
- Written policies **ensure consistency** in setting up and capturing the 3D scans, ultimately improving use of the instrument.

[1] Skelton, Alissa. 2014. "Stothert, Schmaderer Vow to Find Killer of 5-year-old Girl." *Omaha World-Herald*, January 15, 2014.
[2] *KETV*. 2015. "Omaha Man Sentenced for Shooting Death of 5-year-old Girl." April 9, 2015.

Case Study: Laser Scanners Communicated Valuable Context and Enabled Multi-Agency Collaboration During the Investigation of the 2015 San Bernardino Terror Attack.

Michael Russ is a Sheriff's Crime Scene Specialist III for the Scientific Investigations Division, an ISO/IEC 17025:2005 accredited Forensic Science Testing Laboratory, at the San Bernardino County Sheriff's Department in California.

The San Bernardino County Sheriff's Department (SBCSD), with a jurisdiction of over 20,000 square miles, owns 15 three-dimensional terrestrial laser scanners (TLS), with upwards of 60 trained operators. The department conducts in-house training on TLS, with Russ having completed the FARO Laser Scanning Instructor course. SBCSD has deployed their TLS regionally and uses them to document major injury collisions, homicides, and officer-involved shootings.

Terrestrial laser scanners played a role in documenting scenes and evidence from the December 2015 attack on San Bernardino's Inland Regional Center (IRC), where 14 individuals were killed and 22 were seriously wounded in a terrorist attack. The San Bernardino County Sheriff's Department deployed multiple TLS to rapidly document the IRC scene and the positions of the victims. This allowed for victims to be removed from the scene so SBCSD's Coroner Division could undertake the process of identification and next-of-kin notifications.

Simultaneous to the IRC scene, San Bernardino County Sheriff's Department investigators were also using terrestrial laser scanners to document the officer-involved-shooting scene where law enforcement engaged and ultimately overcame the two terrorists responsible for the attack[3]. This scene was over a mile long and involved hundreds of pieces of evidence.

Once they arrived from Quantico, the FBI's Operational Projects Unit also captured additional scans of the IRC scene as well as the entire building complex. By sharing the scans that both groups had captured, the FBI and SBCSD were able to **construct a detailed record of the crime scene** and surrounding area, even though they had used different brands and models of terrestrial laser scanners.

In the following days and weeks, the 3D point-cloud generated from the scene scans were used by multiple different integral partners in the law enforcement and forensic community[4]. The data was able to **provide valuable context to investigators, law enforcement executives and medical examiners** about the events that had taken place at the scenes, without needing to physically bring them into the scene and potentially compromise its integrity. These professionals were able to **easily comprehend spatial relationships** and **identify critical details,** without stepping foot into the scene. The ability of TLS data to virtually place a viewer into the crime scene provides great value to investigators and forensic experts tasked with explaining scenes to attorneys and juries.

> "Data from terrestrial laser scanners provide one of the easiest ways to allow investigators, attorneys and juries to understand a crime scene."
>
> -Michael Russ, San Bernardino County Sheriff's Department

Impact:

- Terrestrial laser scanners allowed the department to **easily share data** with the FBI to merge scans to create a comprehensive account of the scene. Terrestrial laser scanners **enable collaboration between agencies**, even if they own different brands of scanners.
- Scans from these instruments provide virtual access and insight to key stakeholders in cases while **ensuring security and integrity** of the crime scene.

[3] Braziel, Rick, Straub, Frank, Watson, George, and Rod Hoops. 2016. *Bringing Calm to Chaos: A critical incident review of the San Bernardino public safety response to the December 2, 2015, terrorist shooting incident at the Inland Regional Center*. Critical Response Initiative. Washington, DC: Office of Community Oriented Policing Services.

[4] Reconstruction and Analysis of 3D Scenes From Irregularly Distributed 3D Points to Object Classes. Weinmann, M. Springer 2016, XXII, 233 p.

Case Study: 3D Scanning Devices Bring Perspective for Juries in Texas.

Troy Wilson is a Texas Ranger Crime Scene Unit Team Leader. He also serves on the Board of Directors for the Association of Crime Scene Reconstruction and is a member of the Organization of Scientific Area Committees Crime Scene Investigation Subcommittee.

In 2011, the Texas Ranger Crime Scene Investigation Working Group purchased 12 instruments, including multiple Leica P40 devices and the smaller BLK imaging scanners, to aid crime scene investigations. This group uses 3D scanners to investigate homicides, officer-involved shootings, and in some cases, large or extensive scenes.

Most notably, the agency used these systems to survey the mass shooting at First Baptist Church in Sutherland Springs, Texas. A lone gunman, 26-year-old Devin Kelley, entered the church in black tactical gear and opened fire on the congregation with an AR-15 and Ruger AR-556 semi-automatic rifle. The police found 15 empty magazines, each capable of holding 30 rounds. As Kelley left the scene, he engaged in a “shootout” that eventually was fatal. Kelley killed 26 people and wounded 20 others[5], and he died shortly after escaping the scene.

Law enforcement operating a 3D scanner at the Sutherland Springs shooting scene. A NIST calibration tool is indicated in blue. Photo credit: AP Photo (Eric Gay).

The Texas Rangers led the investigation used scanners to collect and preserve evidence. At the church, officers captured the scene and surrounding area with multiple scanners, taking approximately 150 scans. Wilson noted that when practical, users should incorporate a **National Institute of Standards and Technology (NIST) calibration tool** at the beginnings and ends of scene scans to prove in court that the device operated within tolerance errors.

Data from the 3D scanner provide value by showing the spatial relationships in a scene, offering the perspectives of witnesses to the scene, determining bullet trajectories, and **ultimately, corroborating or refuting witness testimony**. Wilson mentioned that 3D scanning provided important perspective in a separate case where a mother had shot her daughter. The scans showed the position of the shooter during the incident, which gave the jury a better understanding of the events that took place during the crime. The prosecutor was able to prove the mother’s guilt because the only position from which the fatal shot could have been taken was that of the mother.

District attorneys who are well-informed regarding the benefits and limitations of 3D scanning can serve as champions for the technology, thereby **increasing the use of 3D scanners in court cases**. Texas prosecutors have successfully used 3D scanning technology in court to provide insight into bullet trajectories and the positions of multiple parties at a scene.

The Texas Rangers have invested in training a significant percentage of their staff on these devices, with 36 trained technology users and 22 software licenses for TruView (Leica’s software platform for sharing point cloud data, design models, mark-ups, and other visualizations from scan data). Extensive training regimes and use keep the Rangers familiar with acquiring and analyzing the scan data clouds captured by the devices. The Rangers have found that information technology support is necessary to enable the effective use of the software and aid prosecutors in scene reconstruction.

Impact:

- Software enables the creation of **2D and 3D representations of the scene** from the data cloud for courtroom use.
- The scans corroborate other evidence suggesting that certain events had taken place during the incident, **providing useful context** for jurors.

[5] Silva, Daniella, Abdelkader, Rima, Williams, Pete, and Phil McCausland. 2017. “Texas Church Shooting: More Than Two Dozen Parishioners Killed.” *NBC News,* November 5,2017.

Case Study: New 3D Scanning Devices Decrease the Time Spent Processing Traffic Accidents, Lowering the Risk of Injuries to Investigators and Reducing Traffic Delays in San Diego County.

Ed Phillips is an accident reconstruction specialist for the San Diego County Department of Public Works (DPW) Traffic Engineering Section. Phillips provided a use profile in the 2016 report (pg. 28).

The San Diego County's DPW primarily uses 3D scanners for motor vehicle crashes and officer-involved shootings. The agency purchased RIEGL VZ-400 instruments and has recently upgraded some models to the RIEGL VZ-400i.

The fact that drivers become impatient waiting for accident scenes to clear often creates a more dangerous situation for responders and other drivers. Faster scans allow crews to remove debris sooner while still preserving evidence. The scan of an accident is equivalent to walking through a tow yard and looking at the damaged vehicle(s). Thus, because the scans are captured digitally, agencies do not need to hold vehicles for years while waiting for trial because the data are easily archived.

The DPW considered several factors when selecting their instrument. The 3D scanner needed **quality engineering** to operate well in California's various weather extremes. Indeed, the system had to be impervious to all weather conditions, including rain, snow, cold temperatures (20°F), and extreme heat (115°F). Officers required **fast scan speeds and data-rich point clouds**. The multifaced system mirror of their instrument projects a lattice of points on the ground, which enables fast data acquisition and creates dense point clouds. The accompanying software has to efficiently register information and **create a clean and clear point cloud** for later processing. Finally, officers need a **lightweight and mobile system**. Conducting scans in difficult-to-traverse terrain is slow, but a mobile system decreases the time spent on the scene.

Another consideration when selecting an advanced system is the need for a computer with sufficient processing speed and memory to handle and process the data. When purchasing the improved scanner, the department also purchased a computer with a more powerful processor to increase the speed of image renderings.

"I can scan a scene in one hour, which used to take six hours with a total station. Each of the scans collect 40 million points and I can process them in less time with the advanced system."

Ed Phillips, San Diego County DPW

Impact:

- Improved data acquisition speed leads to **considerable time savings at the scene,** which influenced the department's decision to upgrade to the VZ-400i model. Faster scans allow crews to process accident scenes, remove debris, and reopen roads sooner, alleviating the pressure that accidents impose on transportation systems. The device helps the DPW work faster without compromising the quality of the evidence gathered.
- The device also allows **time savings while processing and rendering the scans**. The VZ-400i model processes points faster than the previous system, and users can create 2D or 3D renderings within an hour.
- 3D scanning devices enable **preservation of the scene** over time. Agencies prefer to not hold vehicles for an extended time while waiting for trial. The high-quality data collected by the scans are akin to observing the actual vehicle but are easy to store and can be kept indefinitely.
- **Durability** in extreme weather conditions plays a role in choosing the most appropriate 3D scanning device.

Advancements in 3D Scanning Device Technology

While 3D laser scanners were originally created for surveyors, manufacturers have responded to the forensic market with targeted products and software upgrades. Newer models boast improvements, including the following:

- Enhanced performance and functionality
- User-friendliness.

Performance and Functionality Improvements

Manufacturers are consistently improving 3D scanning devices in areas such as including scan rate, point cloud density, and automation. Better cameras and integration tools help investigators create persuasive and data-rich courtroom visuals. As devices become "smarter" and more intuitive, users can quickly analyze a scene and present more compelling evidence for prosecutions. Improvements to processing speeds and enhanced software functionality workflows decrease the time required for data collection and analysis while enabling insightful analysis that may be influential in the investigation.

Faster Processing Speeds

Traffic accidents are especially problematic because distracted or annoyed drivers cause safety concerns for officers and other drivers. Rapid processing is vital to clearing the scene as quickly as possible and ensuring the safety of law enforcement. Newer 3D scanning models operate two to four times faster than their predecessors and can complete a scan in under 1 minute. Multiple products on the market have denser point clouds, which ultimately improve the resolution for processing and courtroom applications. For particularly large scenes, extended scanners can scan over 1 kilometer to collect distant vantage points.

> "Drivers will get impatient, and that makes the situation more dangerous."
>
> Ed Phillips, accident reconstruction specialist

Enhanced Software Functionality Workflow

In addition to 3D scanner device advancements, current software packages are designed to be more intuitive. After investigators use a 3D scanner to collect raw field data in a point cloud, they can import the data into any number of software programs that complement the crime scene. More detail on available software available is provided in the original report within the *Introduction* and *3D Laser Scanning for Forensic Surveying: A Sample Methodology* sections. This software offers automatic features and a range of analyses to match the forensic case needs.

> The State Office of Criminal Investigation in Bavaria uses the integrated High Dynamic Range (HDR) camera in the Z+F Imager 5010C to seamlessly capture color in the point cloud. Previous technology had difficulty merging colorized images because of different lighting conditions. The colorized scenes help **provide spatial impressions** of the environment in courtrooms and investigations.

- The software packages can automatically register multiple point clouds into a congruent and complete image as scans are recorded. Converting the scans into **simple diagrams**, such as overhead views and 2D line drawings, requires little human oversight or knowledge of laser systems.
- Software analytics enable **relevant forensic analyses**, including bullet trajectory analyses, car collision reenactments, vehicle skid mark calculations, crush analyses, blood spatter analyses, 2D and 3D animations, fire animations, pre-incident planning, and advanced scene diagnostics.
- Newer instruments streamline processes and create a chain of custody for the data to **preserve** and **protect** the evidence from tampering.
- Scan patterns, such as panoramas, offer unique image captures that mesh a captured scan with picture images and color.

Departments should consider the additional data storage costs, cloud security, and computer technology required when making purchasing decisions.

Device Ruggedization

Forensic 3D scanners must be able to operate in various conditions. Tight seals, solid construction, and the ability to handle all types of weather are imperative during field work. Outdoor forensic investigations, such as those during car accidents, require operation in wind, rain, and other forms of precipitation. User interviews included investigators who work in harsh climates with extreme high and low temperatures. A primary consideration for these users was the quality of the engineering making the sensors impervious to weather conditions. The various 3D scanners highlighted in this update are water, splash, and dust resistant. Optional features, such as cooling jackets, are available for particularly hot conditions. In addition to ruggedness, manufacturers are creating lighter scanners. Lightweight scanners are more mobile and offer easier set-up and take-down between scans. The improved mobility of these devices decreases the necessary operation time and time on site, which is appreciated by investigators working in difficult weather conditions.

User-Friendliness

3D scanning devices are technically sophisticated instruments that require training to successfully operate. Having users who are comfortable with the technology associated with these scanners is often an adoption barrier to agencies. Agencies may lack the time and resources to adequately train users to the level of confidence needed to use the instruments at a scene or in a courtroom setting. Some manufacturers have designed new scanners with the forensic end user in mind, lowering the barrier to effective use and potentially increasing user confidence. The user experience, workflow, and training support for these products have been a focus of improvement for device companies, including for forensic applications.

> The new RIEGL products offer smart phone applications and a built-in touch screen to help users interact and use the devices.

Enhanced Instrument Usability

Improvements to the user experience of the instrument enable law enforcement to use the device more quickly and successfully. Users of upgraded devices enjoy benefits, such as the following:

- **Easy set-up** that prevents the need for significant technical adjustments when launching the instrument. Many devices can easily adjust to a scene and come with preset calibrations for faster set-up.
- **Intuitive user interfaces** to decrease technical intimidation and increase department adoption. Most products have screens that help guide the user through a scan, some of which are easy-to-use touchscreens.
- Built-in wireless and Global Positioning System (GPS) to **adjust settings remotely** or **automatically track** different scanning positions.
- Ability to **sense position changes** of the instrument, which allows real-time point cloud calculations to ensure that users have captured the entire scene before leaving and improves data registration.
- **Compatibility** with multiple point clouds from different devices, such as handheld scanners, for difficult spaces.

> Smaller units are more portable (e.g., the Leica BLK), and more appropriate for small area scans.

Optimizing the user interface has led to more adoption, efficient use, and completeness when scanning a scene.

Forensics-Specific Scan Workflow

Because 3D scanners use sophisticated technology that considers multiple variables, such as determining the appropriate scan range, lighting adjustments, and scan speed, law enforcement officers may struggle with choosing the correct parameters when operating the instrument at a scene. Manufacturers have designed workflows specifically for forensic applications to eliminate the guesswork for law enforcement and improve scan outputs. Improvements that simplify the forensic application workflow include the following:

- On-site registration automatically compiles scans from the scene to streamline the cloud-to-cloud registration and intuitively assist in data collection. This eliminates the need to register the various scans together into one interactive environment, **simplifying data collection**.
- The devices can **stitch together multiple scan point clouds** in real time to warn users when additional scans are necessary or where obstacles are obstructing a full rendering.
- Registering scans in real time helps avoid the need to return to the scene for images hidden in shadows or poor coverage, leading to **time savings**.
- Scanner poles **add depth and improve scanning accuracy** when the instrument is operating on flat or undistinguished terrain.
- Improvements in device quality **reduce the number of scans required** as the scanners automatically filter and reduce noise from the scans. Larger scenes, however, will need more planning to ensure full coverage and sufficient overlap between scans to build the full environment.

Products built with forensic application-specific design considerations increase the likelihood of success and ultimately build greater confidence in instrument use.

Training Support

Training support ensures that users are up-to-date on the best operating practices and latest software applications to assist investigations. Typically, manufacturers offer in-person fundamental training courses supplemented with live demonstrations and guided mock investigations. Manufacturers also offer additional support through online tutorials and call support for continuing education or for handling complicated situations. For example, training support materials can guide users through troubleshooting scenarios, such as removing a person from a scan who inadvertently entered the device's scanning field.

FARO provides both general training and **specialized forensic application training** on their 3D scanners. The forensic application training specifically demonstrates to participants how to collect and analyze evidence in forensic situations, such as crash reconstruction and projectile trajectory calculations.

Update Conclusion

3D scanner manufacturers are attentive to the forensics market and are customizing scanners specifically for forensic applications. Recent improvements include making devices more intuitive, reducing the need for human input, improving training support, and creating specific workflows for forensic applications. Manufacturers are now offering performance and functionality upgrades aimed at forensic departments' needs, including faster scanning speeds, more points in the cloud, and better software support. Investigators are leveraging these improvements to collect improved evidence to support investigations and prosecution or defense. The FTCoE is currently in the process of organizing a working group to develop a set of standardized methods for obtaining 3D reconstructions at accident and crime scenes using laser scanners.

Table of Updated 3D Scanning Devices from Selected Manufacturers

The manufacturers featured in the original 3D scanning device landscape report have released multiple new products since January 2016. Table 1 provides an overview of the physical specifications of the new 3D scanning products:

Exhibit 1. Physical specifications of the new 3D scanning products.

	FARO		Leica			RIEGL	Z+F
Model	**Focus^S 70/150/350**	**Focus^M 70**	**BLK360**	**RTC360**	**ScanStation PS50**	**VZ 400i**	**Imager 5016**
							
Relative Cost: [1]	$$$ / $$$ / $$$	$$$	$$$	$$$	$$$	$$$	$$$
Software	FARO SCENE	FARO SCENE	Cyclone + Incident Mapping Suite	Cyclone: Field360, Register360, Map360	Cyclone + Incident Mapping Suite	RiSolve	LaserControl
Maintenance calibration [2]	annually	annually	N/A	annually	annually	biennually	annually
Maximum scanning range (reflectivity)	70m / 150m / 350m	70m	Up to 60m	130m	> 1KM (80%)	800m (90%) forensic use 250m (90%)	360m
Scan rate	up to 976,000 pts/sec	up to 488,000 pts/sec	360,000 pts/sec	2 million pts/sec	1 million pts/sec	up to 500,000 pts/sec	up to 1.1 million pts/sec
Field of view	360° (H) and 300° (V)	360° (H) and 300° (V)	360° (H) and 300° (V)	360° (H) and 300° (V)	360° (H) and 290° (V)	360° (H) and 100° (V)	360° (H) and 320° (V)
Laser class	1	1	1	1	1	1	1
Weight	9.3 lbs	9.3 lbs	2.2 lbs	11.7 lbs	27 lbs	24 lbs	16 lbs
Temperature operation range	-5° to 40° C extended range[3]:-20° to 55° C	-5° to 40° C extended range[3]:-20° to 55° C	5° to 40° C	-5° to 40° C	-20° to 50° C	-10° to 50° C low temperature operation[4]	-10° to 45° C
Battery life	4.5 hours	4.5 hours	Typically > 40 setups	4 hours (2 batteries)	5.5 hours (2 batteries)	5 hours	5 hours
Data storage	SD external card	SD external card	SSD internal w/ capacity for > 100 setups	Leica MS256, 256GB exchangeable USB 3.0 flash drive	256 GB internal SSD or external USB	256 GB internal SSD, SDXC external cards up to 512 GB or USB 3.0	128 GB internal
Interfaces	Wireless local area network (WLAN)	Wireless local area network (WLAN)	Wireless local area network (WLAN)	Wireless local area network (WLAN)	Gigabit Ethernet, WLAN, or USB 2.0	LAN interface 10/100/1000 Mbit/sec, USB 3.0, Bluetooth wireless, 3G/4G LTE	SD card slot, ethernet link, WiFi
Warranty	1 year	1 year	1 year	1 year	1 year	2 years	1 year

[1] Relative cost for scanner only. Costs associated with accessories and maintenance agreements are not included.
$: < $60,000
$$: $60,000–$80,000
$$$: > $80,000

[2] Maintenance plans are available for purchase by the manufacturer. Prices vary based on options selected. The Forensic Technology Center of Excellence recommends contacting each manufacturer to explore the best plans based on specific needs of each crime scene unit.

[3] Low temperature operation: scanner has to be powered on while internal temperature is at or above 15°C, high temperature operation: additional accessory required, further information on request.

[4] -20°C: continuous scanning operation if instrument is powered on while internal temperature is at or above 0°C and still air -40°C: scanning operation for about 20 minutes if instrument is powered on while internal temperature is at or above 15°C and still air.

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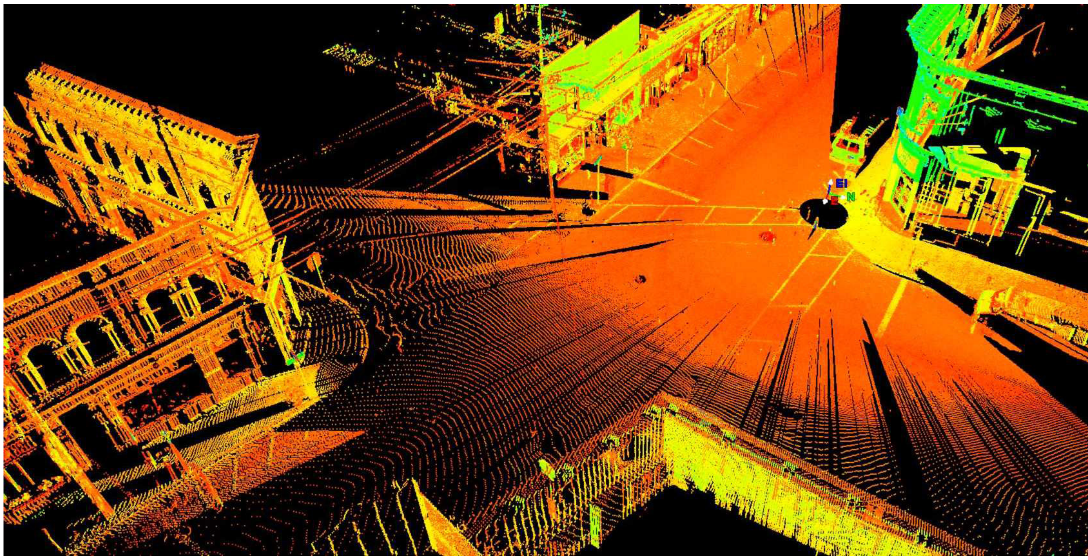
Landscape Study on 3D Crime Scene Scanning Devices

Original Report, January 2016

2018 Update: 11

Landscape Study on **3D Crime Scene Scanning Devices**



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OVERVIEW

The National Institute of Justice's (NIJ's) Forensic Technology Center of Excellence (FTCoE) at RTI International directed this effort, with input from industry, law enforcement, forensic, and criminal justice system communities.

Landscape Study of 3D Terrestrial Laser Scanning Technology

A landscape study, in concept, is designed to provide a comprehensive list of market participants, their products, and product features to enable better-informed decisions by end users. This report provides a "landscape" view of currently available 3D terrestrial laser scanning technology (hereafter referred to as "3D laser scanning technology") and factors impacting their implementation and use. This document is intended to provide crime laboratory directors, practitioners, and stakeholders within the forensic community with a survey of commercially available 3D scanning instruments. Specifically, this report provides decision makers and potential end users with the following:

- exemplary situations that illustrate successful adoption,
- considerations for the implementation of 3D laser scanning technology, and
- comparisons of the capabilities of commercially available 3D laser scanning instruments.

This report is designed to provide the reader with a basic understanding of 3D laser scanning instruments as well as their use, benefits, and limitations. It provides a summary of considerations that will impact procurement, training, fielding, and use. The objectives of this landscape study were as follows:

- Discuss the application of 3D laser scanner technology and instruments as applied to forensic applications.
- Provide the forensic community with an impartial resource that compares the features and capabilities of the available 3D laser scanning instruments.
- Provide considerations from current users to inform potential technology adopters and assist with implementation planning through the use of real-world applications.

3D laser scanning instruments are available for purchase from several vendors. This report explores features, adoption considerations, technical support, and training options to provide a basic overview that will assist crime scene and public safety units, crime scene reconstruction specialists, accident investigators, and crime laboratories in the evaluation process to choose

The following factors led the FTCoE to conduct a landscape study of 3D laser scanning instruments:

- A growing number of crime scene units recognize the benefits of adopting 3D laser scanning instruments that assist with bloodstain pattern analysis, shooting incident reconstruction, traffic collision data collection, and general crime scene reconstruction.
- Crime scene units recognize the added benefits of using 3D laser scanning technology as a means to augment, or replace, traditional crime scene diagrams and provide a record of the scene at a level of thoroughness and accuracy previously unattainable.
- 3D laser scanning instruments provide the ability to use objective methodology to document a crime scene.
- Crime scene units will benefit from an examination of how this technology is chosen, acquired, and implemented as well as benefit from a study that reviews current product offerings, features, and capabilities.

the instrument that best meets their needs. Hereafter, this group of practitioners will be collectively termed "crime scene units." This report only addresses terrestrial, portable 3D laser scanners and does not address handheld or aerial 3D laser scanners.

Research Methodology

To conduct this landscape study, RTI used a process that included the following steps:

- Research secondary sources, including journal and industry literature, to obtain information related to need, successful use, developmental validation, and adoption criteria.
- Discuss the state-of-the-art of the technology with subject matter experts, including crime scene and laboratory practitioners, technology developers, and key decision makers.
- Document, summarize, and release key findings to the forensic community.

Forensic Technology Center of Excellence (FTCoE)

The FTCoE is a collaborative partnership of RTI and its Forensic Science Education Programs Accreditation Commission (FEPAC)–accredited academic partners: Duquesne University, Virginia Commonwealth University, and the University of North Texas Health Science Center. In addition to supporting the NIJ's research and development (R&D) programs, the FTCoE provides testing, evaluation, and technology assistance to forensic laboratories and practitioners in the criminal justice community. The NIJ funds the FTCoE to transition forensic science and technology to practice (award number 2011-DN-BX-K564).

The FTCoE is led by RTI, a global research institute dedicated to improving the human condition by turning knowledge into practice. With a staff of more than 3,700 providing research and technical services to governments and businesses in more than 75 countries, RTI brings a global perspective. The FTCoE builds on RTI's expertise in forensic science, innovation, technology application, economics, DNA analytics, statistics, program evaluation, public health, and information science.

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Please Note: This report is a good faith effort by the FTCoE to accurately represent information available via primary and secondary sources at the time of the analysis. Where appropriate, RTI International has referenced the primary research with individual sources, and similarly, key secondary sources are identified. All other information is a composite view developed from literature, trade press, and stakeholder input.

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GLOSSARY OF COMMONLY USED WORDS AND PHRASES

There are two resources used within the 3D laser scanning and metrology industry that define key terms:

1. American Society for Testing and Materials (ASTM) document E2544–11a: Standard Terminology for Three-Dimensional (3D) Imaging Systems
2. International Bureau of Weights and Measures (BIPM) Vocabulary of Metrology (VIM) issued by the association's Joint Committee for Guides in Metrology (JCGM)

Some of the terminology from these resources is included below; however, both documents contain a more robust collection of definitions.

For the purposes of this document, the following terms are defined:

3D imaging system: A noncontact measurement instrument used to produce a 3D representation (e.g., a point cloud) of an object or a site. (ASTM 3.2)

Bias (of a measuring instrument) (ASTM 3.1): The systematic error of the indication of a measuring instrument. It is impacted by systematic measurement error (VIM 2.17) (primary) and random measurement error (VIM 2.19) (secondary).

Error (of measurement): The result of a measurement minus the true value of the measurement. (VIM 2.16/ASTM 3.1)

Field of view: The angular extent within which objects are measurable by a device such as an optical instrument without user intervention. (ASTM 3.2)

Instrument origin: The point from which all instrument measurements are referenced, that is, the origin of the instrument coordinate reference frame as X, Y, and Z coordinates (0,0,0). (ASTM 3.2)

Light amplification by stimulated emission of radiation (LASER): A device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

Light detection and ranging (Lidar, LIDAR, LiDAR, or LADAR): A remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light.

Measurand: The quantity intended to be measured. (VIM 2.3)

Metrology: The science of measurement and its application. (VIM 2.2)

Measurement accuracy or Accuracy of measurement: The closeness of the agreement between the result of a measurement and a true value of the measurand. (VIM 2.13/ASTM 3.1)

Measurement precision: The closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions. (VIM 2.15)

Measurement bias (VIM 2.18): The estimate of a systematic measurement error.

Measurement rate: The reported points per second. (ASTM 3.2)

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Measurement uncertainty or Uncertainty of measurement: A parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand. (VIM 2.26/ASTM 3.1) The parameter may be, for example, a standard deviation (or given multiple of it) or the half-width of an interval having a stated level of confidence. (ASTM 3.1) Measurement uncertainty is a topic that has been addressed by forensic accrediting bodies as an element of measurement traceability, a requirement for the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 17025:2005 (from the American Society of Crime Lab Directors [ASCLD]/Laboratory Accreditation Board [LAB] ruling on this topic).

Phase shift scanner: A scanner that determines the distance between the object and the scanner by analyzing the phase shift(s) in the wavelength of the return beam compared to the wavelength(s) of emitted infrared laser.

Point cloud: A collection of data points in 3D space (e.g., as obtained using a 3D imaging system). (ASTM 3.2) Each point is a measurement with coordinates relative to the instrument origin. The number of points is often in the hundreds of thousands to millions per scan location, and with the abundance of points, the point cloud not only contains measurements for each point, but the point cloud itself is a visual rendering of the scanned object or location.

Precision: The variability of a measurement process around its average value. (ASTM 3.1)

Registration: The process of determining and applying to two or more datasets the transformations that locate each dataset in a common coordinate system so that the datasets are aligned relative to each other. (ASTM 3.2) Registration combines the point clouds captured at multiple scanning locations at a site into a single, common point cloud representing the entire site that was scanned.

Terrestrial laser scanning: A method for surveying tasks that acquires complex geometric data where each point is determined by the position (X, Y, Z) and the intensity (i) of the returning signal.

Time-of-flight scanner: A scanner that determines the distance of an object by measuring the time required for a pulse of light to travel from the scanner to the object and back.

Total station: A surveying instrument that uses a theodolite with an electronic distance meter to read slope distances from the instrument to a particular point.

True quantity value or True value: The value consistent with the definition of a particular quantity. (VIM 2.11/ASTM 3.1)

Table 1. Classes of Lasers

Class 1	Class 1 lasers are considered safe under all conditions of normal use.
Class 1M	Class 1M lasers are considered safe under all conditions except for when the beam passes through magnifying optics.
Class 2	Class 2 lasers are considered safe because they typically cause a "blink reflex," which protects the eye.
Class 2M	Class 2M lasers are considered safe because of the "blink reflex," unless the beam passes through magnifying optics.
Class 3R	Class 3R lasers are considered safe if handled carefully and with restricted beam viewing. Class 3R lasers can be hazardous where direct beam viewing is involved.
Class 3B	Class 3B lasers are hazardous when direct beam viewing occurs, but diffuse reflections of the laser are considered nonhazardous. Class 3B lasers are generally not suited for survey applications.
Class 4	Class 4 lasers cause eye or skin damage as a result of direct beam exposure. Class 4 lasers are also not suited for survey applications.

Note: Class 1–3R lasers are considered safe for survey in both the United States and in Europe.

INTRODUCTION

Overview of 3D Scanning Technology in Law Enforcement Applications

LiDAR technology was developed in the 1960s for aerial detection of submarines. It has become the gold standard of measurement and is the basis for 3D laser scanning technology used today in multiple disciplines that range from engineering to meteorology to medicine. LiDAR combines laser and radar technology to enable precise, accurate, and objective measurements of the distance of objects by illuminating a target with a laser and analyzing the reflected light. LiDAR has been used by law enforcement personnel for several years, for example, to calculate the speed of vehicles. A handheld laser gun emits a short burst of light that is reflected by the automobile and detected by the device. The elapsed time from pulse to detection, referred to as time-of-flight, is used to determine the distance and, ultimately, the speed of the oncoming vehicle.

The significant benefit to using measurements obtained via 3D laser scanning technology is the accuracy, precision, and objective data collection that the technology provides. The data are collected on the X, Y, and Z axes, and the accuracy of the scan data can be verified multiple ways. Initially, the size, cost, and complexity of the 3D scanning technology limited its use. However, advances such as portability, increased computational speed and memory storage, and higher resolution scanning capabilities have made more applications possible. 3D scanning is now used in many industry sectors to design and manufacture products, inspect systems for quality, and construct buildings. Crime scene units, including those associated with public safety, collision investigation, and scene reconstruction, have implemented 3D laser scanning technology to document and ensure the longevity of a crime scene.

Crime scene investigators must capture an accurate and objective representation of the scene. Still photography or videography combined with the use of traditional measuring equipment (e.g., tape measures and wheeled devices) provide the data for hand-sketched diagrams or for importation into 2D and 3D diagramming software programs. However, obtaining the data for the diagram is contingent on equipment accuracy and the total number of recorded measurements. In addition, these techniques are fairly subjective and dependent on the skills of the operator. But most importantly, hand-recording methods are time- and labor-intensive, most frequently limiting the documentation and diagramming to only evidence and aspects of a scene that seem pertinent at the time of response.[1]

3D laser scanning allows the crime scene investigator to capture the entire geometry of the scene, including evidence and/or relevant aspects of the scene that may not be observed by the naked eye during the original response such as burn pattern evidence. The ability to view and capture the scene through 3D laser scanning technology ensures the longevity and preservation of the scene and provides crime scene units with unprecedented abilities to evaluate the scene and evidence in a holistic manner.

[1] Buck, U., Naether, S., Räss, B., Jackowski, C., & Thali, M. J. (2013). Accident or homicide—Virtual crime scene reconstruction using 3D methods. *Forensic Science International* (Online), *225*(1), 75–84. doi: http://dx.doi.org/10.1016/j.forsciint.2012.05.015

In addition, close- and long-range laser scans can be imported into multiple types of programs that complement crime scene 3D scanning technology.[2] There are a multitude of software packages that span all industries and use 3D laser scanning technology, such as military intelligence, forensics, law enforcement, surveying, film production, graphic design, engineering, and forestry. These programs will accept various forms of scan data to generate a 3D model of the scene. Additional features within the forensic software applications allow subsequent analysis that includes determination of bullet trajectories, bloodstain pattern analysis, and crash analysis pertaining to motor vehicle accidents. The software packages may also include the ability to link still photographs, police reports, and videos to the scan data, which improves the overall presentation and circumstances of the scene. 3D laser scanning technology provides for the ability to test theories of potential scenarios that may confirm or refute presented statements, thereby improving interpretation of the presented evidence.

3D laser scanning technology may also be used in situations where first responder safety is of prime importance, such as biological or radiological contamination events or suspected weapons of mass destruction. The involved areas can be scanned with the equipment while personnel remain a safe distance away, and the full scope of the situation can be ascertained without officers going into the area blindly. 3D scanning technology decreases the time required to collect the necessary data required for accident scene investigation, thereby reducing officer exposure to traffic and the amount of time that traffic builds up at an accident scene.

Examples of Casework Using 3D Laser Scanning

Shooting Incident Reconstruction

3D laser scanning data provide invaluable information to the shooting incident reconstruction specialists. Using 3D laser scanning technology, investigators have the ability to capture and demonstrate trajectories and easily apply demonstrations of industry standard error rates in the form of ballistic cones. Potential firing lines and possibly shooter placement estimations can be made based on trajectories, other evidence placement at the scene, and the general scene layout. Furthermore, this information may be demonstrated in a variety of ways, including static snapshots and dynamic, high-end animations.[3]

Bloodstain Pattern Analysis (BPA)

Software available for BPA 3D laser scanning allows the practitioner to demonstrate a more accurate depiction of the flight dynamics of a blood drop. This analysis represents a significant improvement over the traditional method of stringing that provides only a simple straight-line trajectory of the blood pattern.[4] By using the components of the postprocessing software, the user may also have the ability to represent areas in 3D space where areas of origin for injuries are suspected to have occurred.

Verification of Injury

3D laser scanning data obtained from a scene may be combined with antemortem and postmortem measurements to provide in-depth examination of injury-causing objects or the method in which an injury took place.[5] Current technology can provide full-body 3D reconstruction of injuries as well as collect digitized internal body scans that can be integrated into a complete 3D picture of the deceased. This has the potential to provide detailed insight into the manner in which a person interacted with their death scene environment.

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[2] Davy-Jow, S., Lees, D. M. B., & Russell, S. (2013). Virtual forensic anthropology: Novel applications of anthropometry and technology in a child death case. Forensic Science International (Online), 224(1), e7–e10. doi: http://dx.doi.org/10.1016/j.forsciint.2012.11.002

[3] Haag, M., & Grissim, T. (2008, February 21). Technical overview and application of 3D laser scanning for shooting reconstruction and crime scene investigations. Retrieved on September 9, 2015, from http://www.sparpointgroup.com/images/uploadedFiles/News/PDF/michaelhaag_tonygrissim.pdf.

[4] Buck, U., Kneubuehl, B., Näther, S., Albertini, N., Schmidth, L., & Thali, M. (2011). 3D bloodstain pattern analysis: Ballistic reconstruction of the trajectories of blood drops and determination of the centres of origin of the bloodstains. *Forensic Science International* (Online), *206*(1), 22–28. doi: http://dx.doi.org/10.1016/j.forsciint.2010.06.010

[5] See Footnote 1.

Many 3D laser scanners have the ability to incorporate total station points directly into the 3D scan data. Total stations are survey instruments that capture only one data point at a time; these instruments served as the precursor for the 3D imaging systems on the market today. While use of the total stations may seem redundant, it allows the crime scene unit to choose a workflow incorporating specific targets captured with a total station, while also obtaining the broad scene perspective provided by the 3D laser scanner. Traffic crash scene investigators often view the total station as integral, and this workflow often bridges the gap between total station use and 3D laser scanning.

3D laser scanning technology also has great potential for impacting the ability of a crime laboratory to define "uncertainty of measurement," a growing topic of interest within the forensic realm and a topic that must be addressed by laboratories accredited to ISO 17025 (see ISO 17025 Section 5.4.6). Defining uncertainty provides the ability to answer a question to a specific degree of confidence. To date, many laboratories only focus on the uncertainty of measurement for "critical measurements," but the definition of what is critical is expanding through additional studies of error and uncertainty in forensics.

3D LASER SCANNING FOR FORENSIC SURVEYING: A SAMPLE METHODOLOGY

Every crime scene unit may have a slightly different workflow based on their instrumentation, policies and procedures, and specific needs. The following is an example workflow for a response to a crash or crime scene using 3D laser scanning technology and is intended to serve as a basis for consideration in the development of a crime scene unit's best practice.

Step 1: Respond to the scene with the appropriate 3D laser scanning equipment.

Step 2: Develop a "scan plan" based on the criteria of the scene.

A scan plan includes a general survey of the crime scene to establish the goals of the 3D data collection. Typically, a rough sketch or geographic information system (GIS) site printout can be used to mark the desired positions of data collection, which will be driven by the needs of the case and the location of evidence and relevant features. A scan plan should be thorough enough in scope to effectively capture all relevant data.

A scan plan should consist of

- a sketch of the scene showing where scans should take place,
- a consideration of linking scans to connect scenes, and
- an understanding of the impact that reflectivity has on the return signal in your scanning area.

This is an important step, as the 3D laser scanner can only "see" and therefore scan and capture data for areas to which there is a direct line of sight. The scanner cannot capture data past a visual obstacle. The area beyond an obstacle will appear as a void or blackout, and an appropriate scan plan will accommodate this by ensuring that an adequate number of scan positions are included.

To this end, the number of scans required to appropriately document a scene will vary based on the complexity and visual obstacles within a scene. For example, if a scan is desired from the first and second floor of a home, the operator will need to employ "linking scans" in order to connect the first floor to the second floor in the registration of the scene. The alignment, whether using targets, spheres, or the targetless registration method, as available, will require overlapping targets or scene data to successfully combine these separate areas of a scene into one registered point cloud.

Visual appeal can have a big impact on the scan plan. A scan from a single position will contain sound measurement data, but voids will exist behind any physical obstacle in the scan. To minimize the voids within a scanned area, the user must move the scanner and collect data from as many different positions as deemed appropriate. The number of positions will depend on the complexity of the scene and the importance placed on minimizing the blackout areas.

"Return" is the signal of laser light pulsed to a target that is then detected by the 3D imaging system for a measurement. Laser scanner range is based in part on reflectivity. White and lighter colored surfaces are more reflective (better return), while black and darker colored surfaces are less reflective (poorer return). Range is also based on the angle at which the laser strikes the surface being measured, or the angle of incidence. A smaller or more acute angle of measurement provides a poorer return than an angle of measurement at or closer to 90° (better return). These factors are dependent on one another as well. A highly reflective surface may provide a return at an acute angle, or a poorly reflective surface may provide a useable return when scanned at or near 90°.

An example of the impact of return is with a surface like blacktop pavement. This is a low-reflective surface and typically provides a poor laser return. If scanning a roadway, depending on the make/model of the scanner in use, there may be a need to space the scans relatively close together. However, if the pavement surfaces are not the primary area of interest and objects with better reflectivity populate the scene at scan angles closer to 90°, then a wider spacing may be appropriate over multiple scans, possibly saving time and resources on site.

Step 3: Initiate the laser scanner and follow designated or required quality assurance (QA) protocols.

A QA protocol seeks to increase the degree of confidence in the field data collection. At the conclusion of the QA process, the user may proceed with the documentation of measurements and spatial relationships. This is a performance verification of the 3D laser scanner.

A QA protocol should be defined in an agency's user protocol for 3D laser scanning. The process may include adding something of known size/measurement to the site, and then verifying that the measurement of the object is as expected (to a defined tolerance) within the scan data. This will preferably be completed in the field, but immediate measurability within the instrument interface is make/model dependent.

If an object of known size is used, this is a working standard, and the basis for the "known" should be documented. There are measurement devices that have calibrated "measurement traceability," which should be employed to establish the known measurements used in the quality process.

The QA process may also include internal calibrations and verifications that are also make/model dependent. The internal QA process for a laser scanner prior to data collection should be considered when evaluating 3D laser scanners.

Step 4: Follow the scan plan.

The number of scans and their origins are dependent on evidence location and/or relevant areas of the scene to be scanned. Laser scanners capture scans using different point spacing, or resolution. Resolution may use vendor-specific, preset names (e.g., low resolution vs. high resolution), but the significant aspect is the number of points captured per area scanned. The point spacing becomes relevant when the distance from the scanner increases. Therefore, depending on the distance from the scanner, a higher resolution or points per area may be needed to capture an object or area in sufficient detail for the project.

> Determine appropriate point spacing, or resolution, based on the size of the scene or distance of the object from the scanner. Scanning scenes at different times of the day may provide more desirable points for analysis.

For example, at position #1, a low-resolution, 360° general site scan may be captured. This scan will carry sufficient detail to demonstrate the overall surroundings, but not enough detail to demonstrate the morphology of "crush" damage to a vehicle involved in a crash. A follow-up scan will be captured from the exact same position with a higher resolution scan of crush evidence or any other relevant features that require higher resolution.

These scanners will capture out to varying lengths, some to 300 meters or more, but those captures provide less useful data unless those distance areas are captured at a much higher resolution. This is because the point spacing at that distance is sparse unless manually set to extremely high resolution at the greater distances. This may seem complex, but is useful to consider because a scanner may capture a general scan in 2 minutes or some similar timeframe at a "low resolution." Higher resolutions and larger areas can vastly impact the time it takes to capture a scan.

Scan each position in the scan plan until the scene has been captured to the desired coverage.

Scanning a crime scene can be a simple effort or a complex endeavor. A scan plan may include a multiple-day response such as scanning evidence at night and responding back to the scene during the day to scan with photographic images for more desirable points for output. The spatial integrity of the evidence is captured at the time of collection, and as long as the scene is held (if possible), additional scans can be captured in daylight.

Step 5: Finalize the project. Import the data, and pack up the gear.

There are different interfaces depending on the laser scanner in use, including direct import into point cloud rendering/editing software in the field, to more complex import procedures on desktop or laptop-based workstations containing proprietary software. In many instances, the import must be completed on the scanner-specific proprietary software, but data can be used on third-party vendor solutions or offloaded and combined with other scan datasets, even combining multiple vendors' point cloud datasets.

The scan project will be registered by whatever means was intended at the scene or is used by the vendor-specific solution. This means that either same-named targets will be identified for triangulation and alignment of multiple scans, or visual alignment will be used to visually align multiple scans and allow the software to finalize the alignment.

Step 6: Create the output.

The end goal for 3D laser scanner point cloud data is the creation of effective exhibits that can be used initially during an investigation, in scene reconstructions, and as exhibits in the courtroom. Snapshots, witness views, and animation files are examples of how the data may be presented. Data can be parsed into layers that can be turned on and off to facilitate the demonstration of different perspectives or different evidence types. Exhibits should be such that the data are clear and objective and presented in a manner that can be easily explained to the court. A written report can include all of these outputs and describe their locations. In addition, one might consider consulting with the prosecuting attorney and defense attorney to brief each party on the technology and to demonstrate the capabilities, offering each side the opportunity to request specific exhibits or measurements from the dataset.

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LESSONS LEARNED FROM USER EXPERIENCES

This landscape study provides several real-world examples of the implementation of 3D laser scanning instruments. The discussions captured in this study highlight the agencies' different needs and methods for procurement, training, and implementation.

3D laser scanning technology has gained broader acceptance in law enforcement communities, as the price of the technology continues to decrease and the ease with which the instruments can be set up and used has increased. Although still more expensive than traditional total station instruments, 3D laser scanning instruments provide more encompassing datasets that can be reviewed to uncover evidence that may have been overlooked at the accident or crime scene. 3D laser scanning instruments enable data collection to proceed much more rapidly, thereby increasing public safety in the case of traffic accidents by allowing roads to be cleared much more quickly. Ongoing maintenance costs of the devices are among the key concerns for users, with some of the less expensive devices requiring more maintenance costs over time. Agencies considering the purchase and use of these instruments should also be aware of the need for computers with fast processing speeds and large memory capacities to analyze the scans. The following are potential benefits and implementation considerations:

Benefits offered by 3D laser scanning technology

- Scientifically accurate data: The data provide a completely objective analysis and highly credible evidence in a court of law.
- Thoroughness: Data obtained from scans document the entire scene and may provide spatial evidence first missed as relevant patterns or evidence not obviously visible.
- Longevity: A complete record of the scene is available for subsequent analyses, giving end users the option to revisit the scene and examine the evidence in greater detail.
- Timesaving: Scans of accident and crime scenes can be obtained quickly and easily. In addition, less staffing may be required at crime scenes to document the evidence. This is not universal, and depending on the type, complexity, and needs of a scene, the length of the documentation process will vary.
- Increased public safety: The potential for faster scans may enable accident scenes to be cleared more rapidly, thus decreasing the potential for injuries to law enforcement as well as the motoring public.

Implementation considerations

- Cost of instrument: The availability of funding to purchase instruments may be an issue. The need for multiple scanners to handle throughput at larger crime scene units may also be a challenge.
- Cost of training: Keeping staff trained on the latest software and hardware will be required.
- Cost of maintenance: Annual maintenance costs for calibration and software updates may be significant.
- Postprocessing requirements: Agencies need to keep in mind the need for computers with fast processors and large amounts of memory to process the scan data.
- Portability and ruggedness: Since these devices must travel to accident or crime scenes, they must be easily transported and able to withstand harsh environments.
- Technical support: Agencies should have access to dedicated support that is readily available when technical challenges arise.

- Shared equipment: Law enforcement agencies may benefit by sharing equipment and lessons learned with neighboring jurisdictions.

Training

Most manufacturers or distributors include a 2- to 3-day training course with the purchase of a 3D laser scanning instrument. It is important, however, to consider the extent and additional cost associated with training more and future end users due to increased capacity or personnel turnover. Training for the use of the instrument will be part of the initial purchase costs, but future training will be required for software updates and new or additional instrument features. Departments anticipating a relatively large number of end users may choose to have a few officers certified as trainers, who will then train additional personnel. This model may reduce training costs over the long term while providing consistency in training.

Software Upgrades/Maintenance

Minor software upgrades are provided free of charge by most manufacturers. However, major upgrades (e.g., a new version of the software) will need to be purchased. Manufacturers and their distributors offer maintenance packages that include software upgrades and yearly calibration services. Agencies should factor in the costs associated with the maintenance packages.

Information Technology (IT) Infrastructure Requirements

3D laser scanning instruments require a specific computing infrastructure to process the data from the scans. Data analysis computers must have sufficient power and data storage to run the graphics-intense software. A crime scene unit should evaluate the availability of IT support

Key Questions to Ask

Training:

- What training is provided as part of the purchase price?
- How complex are the processes included in training?
- How much training is needed for scanning scenes vs. completing postprocessing in the software?
- Are both a part of the initial training? Is this covered in a 2- to 3-day class, or is software more of a follow-on intermediate training?
- What resources are provided (e.g., YouTube videos) for self-directed learning and training?
- What is the process for certifying officers to train their own staff?

Maintenance:

- What software/hardware support is included in the purchase price of the 3D laser scanning instrument?
- Are incremental software upgrades covered? How much do major software upgrades cost?
- How much do maintenance packages cost, and what is included?
- How rugged is the instrument? Are data intact if the instrument falls from its stand?
- If a maintenance package is not selected, how much will it cost to calibrate the 3D laser scanning instrument, and how often is recalibration recommended?
- Is a replacement 3D laser scanning instrument provided during the service and/or calibration?

Procurement:

- How will the 3D laser scanning instrument be used, and what advanced features (e.g., targetless registration and integrated global positioning system [GPS]) are preferred?
- How much time (in terms of labor in the field) will this save, and does that warrant the purchase of one or more 3D laser scanning instruments?
- How much time will be saved in postprocessing?
- How often do major software upgrades become available, and how much do they cost?
- What costs may be associated with data processing, storage, and security (e.g., encryption and backup)?
- What other sources of funding, outside of the crime scene unit's established yearly budget, can be explored to pay for the purchase and maintenance of the 3D laser scanning instrument?

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and factor into the cost any additional support, as this will be a key factor for the successful implementation and use of a 3D laser scanning instrument.

Procurement Considerations

Many of the agencies interviewed in this study obtained 3D laser scanning instruments through grants or other funding sources. A clear demonstration of calculated labor savings based on using a 3D laser scanning instrument was a key factor for obtaining support from upper management for the purchase of the instrument.

Leasing a 3D laser scanning instrument may also be a possibility for some agencies. Leasing options are available from some of the manufacturers and distributors. The leasing programs are typically 24 to 60 months with the option to purchase the instrument for an economical rate at the end of the term.

Scanners for Hire

Scanners for hire should also be considered as a stop-gap to start using this technology if it is not currently owned. For example, the company Laser Specialists, in Olathe, Kansas, offers scanners and surveyors for hire. Their clientele typically involve noncriminal or civil job sites, but they have made it clear that if in need, they would partner with law enforcement to provide contracted 3D laser scanning services. Of course, with a private firm, confidentiality may be an issue, but many crime labs have to partner with civilian contractors for services not provided by their lab. This would be no different, and appropriate confidentiality agreements and background investigations may be used as screening tools for hiring contractors.

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USER PROFILES

Subject Matter Experts Shared Insights from Their Product Experiences During Trial Testing, Implementation, and Use

This section provides examples of the successful implementation of 3D laser scanning instruments to illustrate benefits, potential adoption issues, and examples of ways to overcome adoption barriers. The user profiles offer insights on the means by which the technology has been an effective tool for law enforcement agencies. Key impacts and lessons learned are highlighted, followed by examples of successes from the implementation of 3D laser scanning instruments.

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The Clackamas County Sheriff's Office Implemented a FARO® Focus3D X 330 Laser Scanner in 2014

Contributors

Bryon O'Neil is a criminalist for the Clackamas County Sheriff's Office, Oregon City, OR.

User Profile

The FARO 3D laser scanner saved the Clackamas County Sheriff's Office $21,500 per year in reduced overtime.

In April 2014, the Clackamas County Sheriff's Office began employing FARO Focus3D X 330 scanners to document traffic accidents and crime scenes. In the past 18 months, the office has used the scanners to document 25 crime scenes and 44 crash scenes. The decision to purchase the scanners was made after assessing the office's needs for an improved technology, viewing vendor demonstrations, and observing with another crime scene unit. The office felt that the scanner offered major advantages in time and cost savings—both vital considerations to the office. Mr. O'Neil estimates that the scanners are used to document traffic incidents and crime scenes in an approximately 2:1 ratio. The scanner has enabled faster documentation of traffic incidents, resulting in reduced overtime for personnel and quicker response time to reopen roads to traffic after accidents—both significant benefits to workflow. The office uses the ancillary software program Crash Zone by FARO to create both 2D scene maps and 3D renderings of events.

The scanners were purchased with funds gathered from multiple divisions in the office. The initial purchase included the scanner, accessories, training for two officers, and a yearly maintenance agreement. The ongoing expenses remain a major consideration for the office, but the scanners have saved the office approximately $21,500 per fiscal year in overtime, making the annual costs of the instruments a worthwhile investment.

Impact

- The office has had significant savings in overtime pay. The documentation process requires less personnel and consumes less time.
- The office has maximized the use of scanned data through the documentation of bloodstain patterns and bullet trajectories.

Lessons Learned

- Annual maintenance may be a major consideration. A basic maintenance agreement will include yearly calibration and software upgrades, but does not provide loaner scanners during servicing. As instrument maintenance may take up to 5 weeks, the resulting downtime must be considered, unless the unit has more than one scanner.

The San Bernardino County Sheriff's Department uses the FARO® Focus3D X 120 and the FARO® Focus3D X 130 Scanners to Document Crime Scenes

Contributor

Michael Russ is a crime scene specialist (CSS) assigned to the Scientific Investigations Division of the San Bernardino County Sheriff's Department in California.

Use Profile

Due to the volume of end users, the department invested a one-time cost of $15,000 to have Mr. Russ become a certified FARO trainer.

The San Bernardino Sheriff's Department began using 3D laser scanning instruments to document crime scenes approximately 5 years ago; however, in 2014, the department implemented FARO Focus3D 120 and 130 scanners for their ease of use, reduction in setup time, and significant reduction in scan time. In addition, the reduced cost of the FARO instruments allowed the crime scene unit to purchase nearly twice as many scanners. The FARO's single-person setup and operation have significantly reduced the personnel required to scan a crime or collision scene. The department currently has three FARO Focus3D 120 and six FARO Focus3D 130 scanners with over 70 trained users. Due to the volume of end users, the department invested a one-time cost of $15,000 to have Mr. Russ become a certified FARO trainer. He now trains all new end users in the department.

Grant funds were used for all FARO scanner purchases, and although a warranty package with a loaner scanner was available, the department decided that with multiple scanners in-house, some instruments would always be available while others were unavailable due to maintenance or calibration. The department has been very satisfied with the customer focus of the company and finds the software to be user-friendly.

Device Impact

- The implementation of these 3D laser scanning instruments have reduced the time spent scanning and documenting crime and collision scenes.
- The FARO scanners are very light and require only one person for setup and operation.

Lessons Learned

- For large departments anticipating a relatively large number of end users, it may be more cost-efficient to have one or two officers certified as trainers. This department found that doing so yielded more consistent training of additional personnel.

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The Washington, DC, Metropolitan Police Department Has Used Leica Scanners Since 2006 to Document Crime Scenes

Contributor

Officer Grant Greenwalt is assigned to the Crime Scene Investigation Division of the Washington, DC, Metropolitan Police Department.

Use Profile

> "The scanner is useful not only in crime scene documentation, but also in situations where first responder safety is of prime importance, such as biological or radiological contamination events or in cases of suspected weapons of mass destruction."
>
> —Grant Greenwalt

The Washington, DC, Metropolitan Police Department began using Leica scanners in 2006 to document crime scenes based on improved accuracy and resource savings. The 3D scanners can document a crime scene in much less time than manual documentation, which includes sketching and manual measurement, and with far greater accuracy and reduced variability. The scanner is useful not only in crime scene documentation, but also in situations where first responder safety is of prime importance, such as biological or radiological contamination events or in cases of suspected weapons of mass destruction. In these situations, the involved areas can be scanned while personnel remain a safe distance away. The full scope of the situation can be ascertained without officers actually entering the area.

The department purchased the equipment through a grant from the U.S. Department of Homeland Security. Leica provided training to officers, with separate beginning and intermediate scanning courses, and an advanced course on the postproduction of scan data. The department owns three Leica C10 scanners and borrows scanners from other departments for very large scenes to maximize efficiency. The scanner is used in all types of weather conditions, and during heavy rain, the scanner is protected by an inflatable tent.

Device Impact

- The scanner output has been embraced by prosecution and defense attorneys due to its accuracy and impartiality in corroborating or refuting witness statements without bias.
- Use of the scanner has significantly reduced the time and personnel needed to accurately document a crime scene.

Lessons Learned

- Postproduction of the raw scan data is time-consuming, and the extra time required should be considered part of the workflow process.

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The Washington State Patrol Crime Laboratory Has Used Leica ScanStation C10 and P20 Scanners Since 2013

Contributor

Kris Kern is the manager of the Washington State Patrol Crime Laboratory Division's Crime Scene Response Team in Seattle, WA.

Use Profile

There are few disruptions during the capture of a scene. The majority of time is now spent in the postproduction of scan data.

The Washington State Patrol Crime Laboratory implemented the Leica ScanStation C10 and P20 scanners primarily to enhance the documentation of crime scenes. The key factors the department considered for purchase included: accuracy; availability of a National Institute of Standards and Technology (NIST)–traceable, twin-target pole for verification of calibration prior to use; and a wide range of operating conditions under which the scanner can be used. The department internally validated the two instruments using a process developed by Michael Haag from the Albuquerque Police Department Crime Laboratory. The validation included multiple distance measurement verifications with NIST-traceable rulers. The department noticed an initial decrease in workflow after implementation due to the instrument's steep learning curve. Currently, however, there are few disruptions during the capture of a scene. The majority of time is now spent in the postproduction of scan data.

The department purchased its initial scanner (the C10) with grant funds. The second instrument (P20) was purchased through general funds, as will any subsequent units. The purchase price of the C10 included the scanner, twin-target pole, a laptop, one CycloneTM license, and 2 weeks of training for 10 users. The purchase price of the second scanner (P20) included an additional laptop and two additional software licenses. During maintenance or service, the department does not use a loaner scanner. The ongoing costs associated with the two scanners include maintenance for both scanners, three software licenses, and software updates.

Device Impact

- The scanner output has been embraced by prosecution and defense attorneys due to its accuracy. In a team of three, one person is dedicated to scanning the scene.
- Currently, the department has had no issues with court admissibility of the data.
- The system simplifies the ability to share crime scene reconstruction with attorneys.

Lessons Learned

- Ongoing costs, data storage, and security of the data (e.g., encryption and backup) are significant and should be a consideration for implementation.
- Postproduction of the scan data may take up to several days depending on the renderings and animations that are needed.

The North Yorkshire Police Department in the United Kingdom Uses the RIEGL® VZ-400 Scanner for Crime Scenes and Traffic Accident Documentation and Reconstruction

Contributor

Dave Foster is the senior forensic collision investigator for the North Yorkshire Police Department in the United Kingdom.

Use Profile

The fast processing speed has allowed the North Yorkshire Police Department to use the scans and reconstruction data in interrogations and courtroom presentations.

In 2011, the North Yorkshire Police Department began employing a RIEGL VZ-400 scanner to document traffic accidents and crime scenes. The department, in collaboration with other law enforcement agencies, had the opportunity for hands-on experience with Leica, FARO, and RIEGL scanners. The department chose the RIEGL scanner due to its easy setup, rapid scan time, and intuitive software. The RiSolve software allows for completely automated registration and creates 3D renderings of a scene in approximately 10 minutes. A typical scene requires eight scans. The fast processing speed has allowed the North Yorkshire Police Department to use the scans and reconstruction data in interrogations and courtroom presentations. The scanner also is extremely durable and unaffected by weather extremes, including rain, wind, and snow. The department has worked directly with RIEGL to develop firmware to meet its needs, allowing for customization. One example is the ability to set the camera to manual mode, which allows the user to control the settings and ensure proper documentation of the scene. The department has been highly impressed with the collaborative response from RIEGL.

The scanner was purchased through a national rollout grant program. The initial cost included the scanner, accessories, two software licenses, basic and advanced training for the officers, and a 3-year maintenance agreement that includes the use of a loaner scanner during maintenance.

Device Impact

- The fast processing speed makes reconstruction data available during interrogations—a key benefit for investigation.
- Rapid data capture is leading to faster road reopening times, which benefits road users and the wider community.
- Objective and comprehensive documentation of the crime or collision scene provide more data to perform analysis and reconstruction techniques.

Lessons Learned

- The cooperation and support of a crime scene unit's IT department is essential to the success of a scanner's implementation.
- Computers must have sufficient power to run the graphics-intense software, and data storage must be factored in.

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San Diego County's Department of Public Works, Traffic Engineering Section Uses the RIEGL® VZ-400 Laser Scanner to Document Accident Scenes

Contributor

Ed Phillips is an accident reconstruction specialist for San Diego County's Department of Public Works (DPW) Traffic Engineering Section.

Use Profile

> "A scene can now be captured in about 1 hour, as opposed to 3 to 4 hours."
>
> —Ed Phillips

The primary reason that San Diego County's DPW purchased the RIEGL VZ-400 was to significantly decrease the time spent to collect the data required for accident scene investigation. The RIEGL scanner also has been used to document crime scenes. A key purchasing factor was the portability of the instrument. The department wanted an instrument that was portable but still robust and powerful, and felt that the RIEGL VZ-400 fit its needs. The purchase was funded out of the overall general budget as opposed to the department's budget. The department has observed significant time savings in accident scene documentation. A scene can now be captured in about 1 hour, as opposed to 3 to 4 hours. This significantly reduces the safety risks to officers, investigators, and the motoring public, and impedes traffic for substantially less time.

Ongoing cost considerations include software updates and recalibration every 2 years. This instrument does not have yearly maintenance fees, and the initial purchase cost includes the RiSolve software. Adopters may want to also consider purchasing EdgeFX software by Visual Statement, Inc. to create 3D renderings, exhibits, and diagrams for court.

Device Impact

- The device reduces traffic congestion considerably and safety risks after collisions.
- Low maintenance and simple operation positively impact use.

Lessons Learned

- It is imperative for users to be properly trained on the capabilities of the instrument. Proper training and real-world experience are necessary to take advantage of all of the benefits that laser scanning has to offer.
- Laser scanning collects an overwhelming amount of data. The hardware necessary to process this data should be considered as part of the purchase.

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CSI Mapping in Kansas Is a Distributor and User of the Topcon GLS-2000 Laser Scanner Series

Contributor

Steve McKinzie, a retired Kansas Highway Patrol officer, served as the coordinator of the Critical Highway Accident Response teams and is now the owner of the McKinzie Group and CSI Mapping.

Use Profile

> One of the key advantages of the instrument is the speed with which it documents the evidence.

CSI Mapping is hired often to assist in the investigation of motor vehicle crashes. The company uses the Topcon GLS-2000 for documentation of the vehicle after the accident. The instrument is useful particularly in identifying physical objects that may have blocked the view of one of the drivers. The Topcon GLS-2000 can be set up and operational in 5 minutes. Once the device is started, an internal calibration is completed within 3 minutes, and the device is ready to collect data. The Topcon GLS-2000 uses a proprietary format to save scan data. However, once the data are imported into ScanMaster to render the 3D images, they can be exported into a number of different formats for other programs to read. It is imperative that end users follow the appropriate protocols for setting up the instrument, create a reference point, and follow proper departmental protocols for the preservation and presentation of physical evidence in electronic format.

One challenge associated with the instrument is the need for annual calibration. The scanner has to be sent to the corporate office for this, which means shipping internationally and waiting approximately 1 month for the device to be returned. Maintenance plans are available, and Topcon provides the end user with a loaner during recalibration.

Device Impact

- Fast operation time and ease of use decrease the time spent at the scene.
- The capture and presentation of data in court proceedings clarify understanding.

Lessons Learned

- The department should establish solid protocols on instrument setup and measurement.
- The user must be trained and be fluent with the technology.
- Users need to be prepared to process the large amount of data associated with scans.

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The States of Jersey Police Force in the United Kingdom Has Employed a Topcon GLS-1500 for the Documentation of Traffic Incidents

Contributor

Sergeant Jeremy Payne has been employed with the States of Jersey Police Force for over 15 years and has over 25 years of scanning experience, including his time as a civil engineer.

Use Profile

The department has found that the biggest benefit to implementing the scanner has been its ability to document a scene without operator interference.

The States of Jersey Police Force implemented 3D laser scanning technology to document traffic collisions and crime scenes. Topcon was chosen in part because the department already owned a Topcon total station and was familiar with the company. The department has found that the biggest benefit to implementing the scanner has been its ability to document a scene without operator interference. However, because the department does not use the scanner on a frequent basis, 3D renderings take a significant amount of time in postproduction. More familiarity with increased use may resolve this issue. Cases in which scans were obtained by the department have not gone to trial as of yet. However, there have been no admissibility problems with scans that were obtained from a subcontractor. Raw data can be shared on request, particularly to show that the data points have not been manipulated.

The department purchased the instruments using year-end funds. End users in the department were trained for 3 days on the instrument and had additional training on the postproduction of the data. The scanner is calibrated once a year and is not calibrated or verified by the crime scene unit.

Device Impact

- The 3D renderings that are produced have been essential components in court cases.
- The quality of the data captured exceeds previous collection methods.

Lessons Learned

- Significant time should be dedicated to postproduction.
- It is imperative that users stay current with scanning and software skills.
- The 3D renderings are appreciated in court; this demand may increase workload and time in postproduction.

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Visual Sciences, Inc. (VSI) Uses Zoller+Fröhlich (Z+F) Laser Scanners to Develop 3D Modeling and Computer Graphics that Provide Clients with Accident Reconstruction

Contributor

Dr. Anand Kasbekar is the president of VSI and has extensive experience with traffic accident investigation. His company works with clients to address liability claims and presents data from traffic accident scans in civil court cases. He has used data from the scanner multiple times as part of legal defense. The data have been admitted and not contested in courts of law.

Use Profile

> "The scanner does an excellent job at capturing all objects in a scene, but results in large data files that require computers with fast processors and large amounts of storage."
>
> —Anand Kasbekar

VSI purchased a Z+F scanner to use as high-definition, portable device to digitize larger objects. The size of the objects may range from 5 feet tall to a four-story building. The Z+F scanner has an excellent ability to collect data in bright conditions, even on darker objects. It does an excellent job at capturing all objects in a scene, but results in large data files that require computers with fast processors and large amounts of storage. Often, the bottleneck in the workflow is the data processing. The scanner is portable, yet rugged and durable. For example, on one occasion, the scanner accidently fell over 5 feet, but it remained intact, operational, and in calibration—there was no adverse effect on the collected data.

The purchase includes 3 days of training and a 1-year warranty. Every year, the scanner is sent to the Pittsburgh office for maintenance and recalibration. VSI coordinates the downtime associated with having the scanner recalibrated so that a rental unit is not required, although Z+F offers this option if necessary.

Device Impact

- The data collected are essential to investigation and superior to previous manual methods.
- The scanner picks up all potential pieces of evidence. On numerous occasions, reviewing the scan data revealed evidence that was originally missed at the accident scene.

Lessons Learned

- The operation of the scanner, and even more so the data processing, requires training and experience to master. It may be challenging for someone who uses the device infrequently to remain proficient with regard to operation and data processing.
- Because of the critical nature of accident investigation, it is important to have reliable and durable scanners.

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3D SCANNING TECHNICAL PRODUCT LANDSCAPE

The 3D laser scanning market is well established. Increased adoption of the technology is due primarily to lower hardware and software costs as well as the increasing ease with which point clouds generated by the scanners can be converted to computer-aided design (CAD) models.[6] As prices continue to decline and the legal and public safety benefits of using these instruments become more publicized, the law enforcement community will continue to incorporate 3D laser scanning technology for crime and accident scene documentation. Overviews of six manufacturers of 3D laser scanning instruments are provided below. Table 2 provides a direct comparison of select features for each product.

Table 2. Overview of Features for Select 3D Laser Scanners

Relative cost for scanner only. Costs associated with accessories and maintenance agreements are not included. $: <$60,000 $$: $60,000–$80,000 $$$: >$80,000	FARO® Focus3D X 330	Leica ScanStation PS40	RIEGL® VZ-400	Topcon GLS-2000M	Trimble® TX8	Z+F Imager® 5010C
						
Relative cost	$	$$$	$$$	$	$$	$$$
Software	FARO SCENE	Cyclone™ SCAN	RiSolve	ScanMaster	RealWorks	LaserControl
Maintenance calibration*	Yearly	Yearly	Every 2 years	Yearly	Yearly	Yearly
Maximum scanning range (reflectivity)	330 m (90%)	270 m (34%)	600 m (90%)	350 m (90%)	120 m (90%)	187 m (unknown)
Scan rate	Up to 976,000 pts/sec	Up to 1,000,000 pts/sec	Up to 122,000 pts/sec	Up to 120,000 pts/sec	Up to 1,000,000 pts/sec	Up to 1,000,000 pts/sec
Field of view	360° (H) and 300° (V)	360° (H) and 270o (V)	360° (H) and 100° (V)	360° (H) and 270° (V)	360° (H) and 317° (V)	360° (H) and 320° (V)
Laser class	Class 1	Class 1	Class 1	Class 3R (high speed)/ 1M (low power)	Class 1	Class 1
Weight	12 lbs	28 lbs	21 lbs	22 lbs.	24 lbs	24 lbs
Battery life	4.5 hrs	5.5 hrs	4 hrs	5 hrs	2 hrs	3 hrs
Data storage	Secure Digital (SD) external card	256 GB internal solid-state drive (SSD) or external USB device	32 GB internal	SD card up to 32 GB capacity	USB external drive	64 GB internal SSD, 2 x 32 GB USB external drive
Interfaces	Wireless local area network (WLAN)	Gigabit Ethernet, WLAN, or USB 2.0 device	Local area network (LAN), WLAN, USB 2.0	None	USB 3.0	Gigabit Ethernet, WLAN, or USB 2.0 device
Warranty	1 yr	1 yr	1 yr	1 yr	1 yr	1 yr

*Maintenance plans are available for purchase by the manufacturer. Prices vary based on options selected. The Forensic Technology Center of Excellence (FTCoE) recommends contacting each manufacturer to explore the best plans based on specific needs of each crime scene unit.

[6] SPAR Point Group, (2015). 3D laser scanning market to hit $4.08 billion by 2018. Retrieved from http://www.sparpointgroup.com/news/reverse-engineering/3d-laser-scanning-market-to-hit-408-bil-by-2018.

FARO, Inc. (http://www.faro.com/)

FARO has been making instruments of metrology for over 30 years and markets its latest long-range instrument, the FARO Focus3D X 330, to law enforcement agencies. FARO has a division devoted to forensic metrology, and ts customer base includes law enforcement agencies, private reconstruction specialists, the Federal Bureau of Investigation (FBI), the Naval Criminal Investigative Service (NCIS), the Secret Service, and the U.S. Department of Transportation. Scans from FARO instruments have been used as evidence in over 50 court cases. FARO currently produces the X 130 and X 330 scanners, which are the most popular models used by the law enforcement community.

Unique Features

- The scanner is lightweight and self-leveling. Setup time in the field is minimal, and scans can be collected by a single user.
- FARO's instruments use third-party software for accident reconstruction, bloodstain pattern analysis, and bullet trajectory analysis.

[7] The C10 and P20 models were mentioned earlier in this report and are older versions of the Leica scanners used by crime scene units.

Leica Geosystems, Inc. (http://www.leica-geosystems.us/)

Leica Geosystems was founded in 1921 and has produced instruments for high-accuracy and mapping applications for almost 100 years. The company provides forensic solutions to public safety agencies and private forensic practitioners that meet the accuracy, accreditation, and legal standards required to go from the crime/crash scene to the courtroom. The Leica ScanStation has been successfully vetted by multiple Daubert hearings (including a ruling by a federal judge) and has been extensively studied and cited in many peer-reviewed publications. Information on instrument accuracy, precision, and uncertainty of measurement, as well as information about validation and testing procedures, is readily available. Data from Leica ScanStation instruments have been accepted as both scientific and demonstrative evidence in U.S courts. Leica currently offers three survey-grade laser scanning solutions: the ScanStation PS16, PS30, and PS40[7].

Leica specializes in providing turn-key solutions for customers and a wide range of customization options, such as consulting in support of accreditation processes under ISO standards and advanced workflow training for specialized applications. The Leica software product portfolio includes several robust software solutions, including the easy-to-use Leica Geosystems Incident Mapping Suite, which includes options for Leica's popular Cyclone software. Many other software options are also available.

Unique Features

- Leica's instruments have a single-point 3D positional accuracy of 3 millimeters at 50 meters and 6 millimeters at 100 meters.
- Optics are all weather-protected for use in rain, snow, and dusty conditions thanks to an ingress protection rating of IP54.
- Leica's instruments have an internal high dynamic range (HDR) imaging system with streaming video including a zoom function.

RIEGL USA, Inc. (www.riegl.com)

RIEGL is a global provider of advanced 3D laser scanning solutions with operations in the United States, Austria, Japan, and China. The company has almost 40 years of experience in the research, development, and production of laser range finders, distance meters, and scanners. The company markets its proven and ultra-versatile V-Line® 3D laser scanning instruments, specifically the RIEGL VZ-400, to the criminal justice and law enforcement communities.

RIEGL serves customers worldwide, with renowned customers such as the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Secret Service, and FBI. In the U.S. police sector, RIEGL is currently working with the Florida Highway Patrol, South Carolina Highway Patrol, San Diego Police Department, and San Diego DPW to incorporate the RIEGL VZ-400 into accident investigation protocols. Data from the RIEGL VZ-400 have been successfully used in court by the San Diego Police Department. Internationally, RIEGL VZ-400 scanners have been successfully employed by the Metropolitan Police in the United Kingdom, several police forces in Zurich, Switzerland, and by the Queensland Police in Australia. RIEGL offers a highly advanced and proven workflow with reference users all over the world. The RIEGL VZ-400 system includes the hardware, software (RiSolve), and a 3-day training course that addresses hardware operation, software processing, and best-practice workflows. Technical support for the product is provided for the life of the product. The warranty for the RIEGL VZ-400 is 1 year; annual maintenance packages can be purchased at an additional cost. The company will provide loaner scanners under these maintenance packages. RIEGL also recommends nitrogen purges every 2 years and a system check.

Unique Features

- In addition to the industry-standard 5-megapixel internal camera, an external 36-megapixel camera enables the RIEGL VZ-400 to acquire images rapidly, generate precise measurements, and provide realistic renderings of the scene.
- The laser combines RIEGL's echo digitization and online waveform processing to enable superior measurement capability even under adverse atmospheric conditions.

Topcon Corporation (https://www.topconpositioning.com/forensics)

Topcon markets its compact, high-speed 3D laser scanning instrument, the GLS series, to the criminal justice and law enforcement communities. The Topcon GLS-2000 is offered in three models: GLS-2000S (short range), GLS-2000M (medium range), and GLS-2000L (long range). Each model provides fast, precise, full-dome scanning with user-selectable measurement range settings. Each scanner model is also available in a money-saving bundle package that includes a single license of ScanMaster software. The data generated from scans are stored on SD cards, which can then be transferred to a laptop for editing and imported into specialized forensic mapping software for analysis.

The company sells its products through distributors; the primary distributor for forensics applications is CSI Mapping (https://www.csimapping.com/). With the purchase of the Topcon GLS-2000, CSI Mapping provides a 3-day training class.

Topcon offers a 12-month warranty on the Topcon GLS-2000, with the option of purchasing another year of warranty protection. Annual maintenance packages are also offered through the distributor. The company recommends calibrating the devices once a year. Topcon does not provide a loaner during calibration; however, distributors that offer maintenance agreements may include a loaner instrument as part of the agreement. Major software upgrades are offered on a "fee" basis, but incremental upgrades are provided at no charge and can be downloaded from the TotalCare support Web site.

Unique Features

- Two 5-megapixel cameras (wide-angle and telephoto) provide vibrant images that can be tied to the point cloud for true coloring.
- Instrument height can be accurately measured via a laser plummet function, enabling faster and more accurate setup times.
- Laser output can be switched between Class 1M and Class 3R to prevent eye damage in populated areas.

Trimble Navigation Limited (http://www.trimble.com/)

Trimble's geospatial group offers a comprehensive range of 3D laser scanning instruments for the rapid collection of data. Trimble's law enforcement applications for 3D laser scanning center around detailing a collision or crime scene quickly and thoroughly. Users are able to sufficiently capture data for analysis so that measurements can be extracted directly from crime scenes using Trimble-specific software. The Trimble® TX8 typically is used for forensic purposes. This instrument gathers 1 million points/second with a typical scan time of only 3 minutes by using Trimble's patented Lightning™ technology. The Trimble TX8 loads directly into the Trimble RealWorks® software, which provides efficient data flow into CAD programs and is included in the equipment purchase. Trimble offers extensive technical training, even providing a Web site to this purpose: the Trimble Knowledge Network. Trimble's RealWorks onboard software is intuitive, so users can quickly manage scan resolution and define scan areas by only capturing necessary information and providing flexibility to the user.

Unique Features

- Trimble's instruments have long-range capture: 120 meter standard up to a maximum range of 340 meters with an optional upgrade.
- Trimble's instruments provide a wide range of view: 360° x 317°.

Z+F USA, Inc. (http://www.zf-usa.com/)

Z+F is a German company that is considered a worldwide leader in electronic control equipment and has been developing innovative electronic products since 1963. Z+F developed an optical laser scanning system that has many applications, including industrial, architectural, infrastructure, and forensics. Z+F, headquartered in Bridgeville, Pennsylvania, was founded in 1998 to distribute and support 3D laser scanners and software in the Americas. Z+F serves customers worldwide, with the highest number of forensic applications of its lasers in Germany and Europe.

Z+F IMAGER® 5010C and 5010X are the two scanners typically used for crime scene investigation. LaserControl® Scout software keeps a constant link to the scanner so that after a scan is finished, the data are downloaded onto the tablet PC automatically, and the software immediately attempts a preliminary registration. The software also assists the user with the early detection of scanning positional gaps and fills in the gaps immediately with additional scans to ensure the dataset is complete. Training can be either on a Z+F premise, on a customer site, or online. Refresher trainings are offered as webinars. Technical support consists of phone, e-mail, remote sessions, and webinars.

Unique Features

- Standalone devices with integrated batteries and color display touchscreens offer ease of use.
- The devices have a large 320° x 360° field of view.
- Devices offer HDR image quality and high accuracy and speed.
- LaserControl Scout offers automatic registration, data quality checks, target quality checks, and finds and fills gaps with additional scans.

OTHER KEY CONSIDERATIONS FOR AN INFORMED DECISION

Throughout this report, key considerations such as cost and time savings, training, maintenance, and court acceptance were discussed by stakeholders and vendors, yet there are additional considerations that an agency should also investigate prior to make a decision to purchase and implement 3D crime scene imaging technology.

As crime scene units assess the potential of 3D scanning technology for use in their respective organizations, this section outlines some important considerations, as well as device features, that should be taken into account prior to purchasing a 3D scanner.

Error and Accuracy

Error and accuracy are critical aspects in verifying that the scanner selected for purchase has the capabilities to produce the survey-grade measurements using sound methodology that will stand up against Daubert or Frye hearings in court proceedings. Error and accuracy are terms that can be presented differently by different vendors. An analysis of accuracy claims is beyond the scope of this landscape study. The FTCoE recommends working with each vendor to assess accuracy claims. ASTM E2938–15 is the Standard Test Method for Evaluating the Relative-Range Measurement Performance of 3D Imaging Systems in the Medium Range. This document was issued by ASTM Committee E57 on laser scanning and is designed to help establish a relative comparison point for different instruments.

In July 2015, NIST hosted the Forensic Science Error Management Symposium[8] in Washington, DC. At that symposium, presentations were made specific to error in 3D laser scanning, including a presentation by Dr. Meghan Shilling on 3D Laser Scanner Error Sources and Dr. Gregory Walsh on Measurement Errors with Point Clouds.

Range and Speed

The range of an instrument is dependent on the reflectivity of the object being scanned and the angle of incidence of the laser scanner to the surface. These two variables can drastically impact the return of the data points, and a buyer should consider evaluating a vendor's instrument return under different scanning scenarios, keeping in mind what conditions exist in the buyer's "real world." In addition, the speed of a single scan depends on the resolution or number of points scanned per area. When considering any instrument, be mindful of higher resolution scan times. Range and speed are often discussed in terms of the vendor's best-case scenario, but actual operation may differ in a real-world event based on specific needs of a crime scene.

Independent Research

This report is thorough, but it is not all-encompassing. Laser scanning is a hot topic, not only within forensics, but across all industries that use the technology. There is an abundance of scholarly publications, research reports, and technical articles on laser scanning. The literature review for this report lists many of these publications, and the direct consumption of this material is advised for those preparing to engage in the acquisition and use of a 3D laser scanning instrument.

The "Test Drive"

Many vendors will arrange for an on-site demonstration of their instrumentation. If this is possible, it is important to make use of this experience. The equipment can be used to scan

[8] http://www.nist.gov/director/international_forensics_home.cfm

scenarios that will mimic real-life cases designed by the potential purchaser. These scenarios can be presented to multiple vendors, and the scan process and output for these situation-specific scenes can be used to assist in the decision-making process.

Social Media

This is the social media era. There are a wide range of laser scanning groups on Facebook, Yahoo, and LinkedIn, to name a few. There are laser scanning forums on laser scanning Web sites. There are broad topic sites and vendor-specific sites. One could set a Twitter search term for "laser scanning," "laser scanner," and any vendor-specific term, and hundreds of responses will populate. There are sites specifically devoted to the application of laser scanning in forensics and law enforcement. These sites will provide access to fellow users and a whole wealth of resources, especially in post-acquisition protocol and QA practices development.

Resources

For those practitioners implementing 3D laser scanning technology, resources are available to assist with adoption. Multiple organizations and associations monitor the improvements in this technology and document the admittance and use of 3D laser scanning data in court proceedings. This information may be maintained in databases of case law from various jurisdictions and judicial districts. In addition, many of these same organizations serve as a clearinghouse for training opportunities, sharing of policies and procedures, and standardization of the technology throughout the field. Table 3 lists some resources for consideration.

Table3. 3D Laser Scanning Resources to Provide Assistance with Technology Adoption

3D Laser Scanning Resources	Web Site
International Association of Forensic and Security Metrology (IAFSM)	http://www.iafsm.org/
American Society for Testing and Materials (ASTM)	http://www.astm.org/
International Bureau of Weights and Measures (BIPM)	http://www.bipm.org/
SPAR Point Group	http://www.sparpointgroup.com/
Terrestrial Laser Scanning International Interest Group (TLSIIG)	http://tlsiig.bu.edu
The Laser Scanning Forum	https://www.laserscanningforum.com/index.php

SUMMARY

A growing number of crime scene units recognize the benefits of adopting 3D laser scanning instruments to assist with bloodstain pattern analysis, shooting incident reconstruction, traffic collision data collection, and general crime scene reconstruction. The goal of this landscape study is to provide the reader with a basic understanding of 3D laser scanning instruments as well as their use, benefits, and limitations. This report explores features, adoption considerations, technical support, and training options to provide a basic overview that will assist crime scene and public safety units, crime scene reconstruction specialists, accident investigators, and crime laboratories in the evaluation process to choose the instrument that best meets their needs. The report also provides suggested methodologies for incorporating a 3D scanner workflow to help establish best practices for responding to a crash or crime scene.

LiDAR has become the gold standard of measurement and is the basis for 3D laser scanning technology used today in multiple disciplines that range from engineering to meteorology to medicine. Crime scene units, including those associated with public safety, collision investigation, and scene reconstruction, have implemented 3D laser scanning technology because of the significant benefits the technology provides, including:

- Scientifically accurate data: The data provide a completely objective analysis and highly credible evidence in a court of law.
- Thoroughness: Data obtained from scans document the entire scene and may provide spatial evidence first missed as relevant patterns or evidence not obviously visible.
- Longevity: A complete record of the scene is available for subsequent analyses, giving end users the option to revisit the scene and examine the evidence in greater detail.
- Timesaving: Scans of accident and crime scenes can be obtained quickly and easily. In addition, less staffing may be required at crime scenes to document the evidence. This is not universal, and depending on the type, complexity, and needs of a scene, the length of the documentation process will vary.
- Increased public safety: The potential for faster scans may enable accident scenes to be cleared more rapidly, thus decreasing the potential for injuries to law enforcement as well as the motoring public.

This landscape study provides several real-world examples and lessons learned from the implementation of 3D laser scanning instruments. The discussions captured in this study highlight the agencies' different needs and methods for procurement, training, and implementation. Key questions to ask related to each of these areas are provided. A summary of important considerations are provided below.

- Cost of instrument: The availability of funding to purchase instruments may be an issue. With costs that can extend into six figures, the need for some of the advanced features (e.g., targetless registration, integrated GPS, and very fast scan times associated with high-end laser scanners) should be considered for those with limited budgets. The need for multiple scanners to handle throughput at larger crime scene units may also be a challenge.
- Cost of training: It is imperative for users of scanning equipment to be properly trained on use and presentation to law enforcement and courts of law. While the cost of initial training may be provided as part of the

purchase, keeping staff trained on the latest software and hardware will be required and should be factored in as an ongoing expense.

- Cost of maintenance: Costs associated with maintenance agreements should be considered as part of ongoing expenses to operate the instrument. Maintenance agreements that may include yearly calibration and software upgrades may be purchased from most manufacturers.
- Postprocessing requirements: Processing the scans requires computer equipment that is up-to-date and has sufficient power and memory to run the graphics-intense software. Crime scene units need to keep in mind the need for computers with fast processors and large amounts of memory to process the scan data.
- Portability and ruggedness: Since these devices must travel to accident or crime scenes, they must be easily transported and able to withstand harsh environments.
- Technical support: Crime scene units should have access to dedicated support that is readily available when technical challenges arise.
- Shared equipment: Law enforcement agencies may benefit by sharing equipment and lessons learned with neighboring jurisdictions.

3D laser scanners offer crime scene units an excellent tool to increase the speed and efficiency of data collection. While the use of 3D laser scanning instruments in these communities is still relatively new, the technology has seen increased use in applications that include accident analysis and reconstruction and crime scene documentation, such as blood spatter and bullet trajectory analysis. Prices of 3D laser scanning instruments have decreased significantly over the last 10 years and will continue to do so. As prices continue to decline and the legal and public safety benefits of owning these instruments become better known, crime scene units will increasingly rely on the benefits 3D laser scanning technology offers.

APPENDIX A

To learn more about mobile 3D scanning technology, consider these additional resources.

Crime Scene Documentation

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