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.
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.
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.

In addition, close- and long-range laser scans can be imported into multiple types of programs that complement crime scene 3D scanning technology. 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.

**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. 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. 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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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.
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 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

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

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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 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.

“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 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
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.
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.

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.