Technical Advances in the Visual Documentation of Crime Scenes: An Overview

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1. Introduction

The documentation of crime scene images is essential to both the criminal investigation and judicial process. Two-dimensional (2D) and three-dimensional (3D) imaging used to document crime scenes can include traditional still photography, videography, panoramic photographic imaging, and multidimensional laser scanners. The latter two technologies complement the first two by comprehensively and efficiently recording high-resolution, 360° images or data. The benefits of panoramic photographic imaging and multidimensional laser scanners include having a digitized "walk-through" of the crime scene. This capability has led criminal justice agencies to adopt this technology for crime scene documentation.

Uses for Panoramic Imaging Technologies
- Pre-collection evaluation of crime scene
- Post-release evaluation of crime scene
- Documentation of spatial relationships
- Development of more compelling courtroom exhibits
- Vehicular crash scene reconstruction
- Trajectory analysis
- Fire and explosion scene documentation
- Witness and victim perspective analysis
- Search warrant documentation
- Property and security management

As with any technology, law enforcement agencies need fact-based information regarding the challenges and benefits of panoramic photographic imaging to properly adopt this technology and realize its true value. Accordingly, the Department of Forensic Science at Virginia Commonwealth University (VCU) through the National Institute of Justice (NIJ) Forensic Technology Center of Excellence (FTCoE), led by RTI International, conducted an evaluation of panoramic imaging technologies used for crime scene documentation. The purpose of this evaluation was to objectively compare three different panoramic imaging technologies to assess the capabilities, requirements, and challenges of each technology.

The evaluation addressed ease of setup, system calibration, system operation, technology capability under varying scenarios, software processing, and final output preparation. In addition, the evaluation collected information regarding hardware and software requirements, pricing, and training commitments. The three panoramic imaging technologies selected for this evaluation were (1) SceneVision-Panorama, (2) Panoscan MK-3, and (3) Leica ScanStation C10.

A more detailed, results-driven evaluation report is also avalilable on the FTCoE website, www.forensiccoe.org. This longer report provides more in-depth information for each of the evaluated imaging technologies, including graphics, photographs, and technical details.

2. Background

This section discusses the evolution of the visual documentation of crime scenes, from the traditional use of photography to the adoption of panoramic imaging technologies. This discussion includes a literature overview of the application of panoramic technologies in communities other than forensic science and how these technologies came to be used for criminal justice purposes.

2.1 Panoramic Imaging and Crime Scene Documentation

For more than a century, photography has been an effective tool in the investigation of crime scenes, with specialized applications for firearms, fingerprints, and ultraviolet photography for bloody shoe prints being introduced in 1902, 1905, and 1934, respectively. With the eventual movement of photography from the black and white media of the 1940s to digital imaging, the admissibility of digital photos in the courts was challenged in the mid-1990s and involved several landmark cases, including *State of Washington vs. Eric Hayden* (1995) and *State of California vs. Phillip Lee Jackson* (1995). In both cases, photography in digital format was accepted and pivotal to the final court decision. In 2004, the case *State of Connecticut v. Alfred Swinton* clearly defined the standards of admissibility in the Federal Rules of Evidence 901, which are commonly known as the "Swinton Six." Digital photography and the advent of specialized software made possible the ability to "string" photos together in a panoramic fashion that presented the spatial documentation of evidence in the context of the crime scene. In recent years, panoramic scanners have been adopted for crime scene documentation.[1,2]

Conversations with Tony Grissim of Leica Geosystems, Ted Chavalas of Panoscan, and Nick England from 3rd Tech have explained how panoramic scanning technologies were originally developed for corporate and university research, as well as commercial purposes. These technologies were developed out of the demand for "virtual reality" content that was easy to create and use, particularly with the advent of faster and more efficient computer hardware and software. Early adopters of a virtual reality or panoramic technology were automobile manufacturers, oil companies, engineering and construction firms, realtor companies, and major hotel chains. Law enforcement and forensic science early users or adopters of scanning technologies included the Queensland Police in Australia, the FBI, and the Kern County Sheriff's Office (Bakersfield, CA). The use was not widespread in the early days, particularly since the equipment was cumbersome and not necessarily easy to maneuver. However, agencies began to see the high value of the panoramic products for investigations and the courtroom. In 1999, the FBI deployed the first generation of ScanStation to reconstruct a shooting incident in Oregon, after which Leica formed a Public Safety Group with a mission to support law enforcement and guide the development team. After the events on September 11, 2001, Panoscan shifted focus from commercial sales to law enforcement applications. 3rd Tech's SceneVision-Panorama software program was developed from the software used to process data for their 3D laser scanning equipment and has been marketed solely to law enforcement, accident, and fire investigation agencies.

Panoramic imaging technologies have been used widely in other fields, including manufacturing quality control, architectural restoration, and geomorphology.[3,4,5,6,7,8] These applications illustrate the testing and validation of this technology, explore its strengths and limitations, and indicate its potential value for law enforcement. For example, panoramic technologies have been used to help evaluate real surfaces from scanned objects in architectural and cultural heritage-based work and to manage the 1 million plus measured points in the scan more efficiently.[9] Three-dimensional urban models have also been developed for city planners[4] and have been evaluated to assess the work of a twin-disc fertilizer spreader,[10] water and soil surface elevations, and sprinkler irrigation jets.[6] A method to fully automate the collection of three-dimensional measurements of cultural heritage objects without touching them has also been evaluated successfully,[9] and three laser scanners were objectively evaluated for engineering and surveying applications.[11]

In addition, algorithms have been developed to deal with dynamic subjects and large-scale lighting variations in any application,[12] as well as the correction of color mismatches in the assembling of data and images.[13] These studies were performed for non-forensic science purposes with relative success to describe uses and limitations for their specific applications and also provided direction for future equipment developments. In addition, they illustrate authentication requirements and the need for more efficient software processing. Assuredly, the results in the peer-reviewed literature will have an overall positive impact on the development of the technology, even as it applies to crime scene investigations and other forensic science purposes.

To date, a formal evaluation, comparison, or hypothesis-driven experiment of panoramic imaging technologies as they apply to the documentation and analysis of crime scenes could not be found in traditionally peer-reviewed literature. Published recommendations were found for the use of these technologies in the investigation of sea piracy in which flammability and low-light conditions are of concern,[14] and a hand-held 3D laser scanner was proposed as a method to document transient and impression evidence.[15] Case studies have also described using a scanning technology for analyzing blood stain patterns[16]and for trajectory analyses.[17] Furthermore, technologically advanced exhibits in trial proceedings, such as scene “walk-throughs” and “zoom-in” capabilities, that result from technologically advanced documentation of scenes, such as panoramic imaging, have been described and advocated for strongly in the literature.[18, 19]

In addition to these few findings in the relevant literature, agencies have indicated that they have adopted panoramic imaging technologies for a multitude of needs and specific applications. Some agencies described sending a scanning team into a scene prior to the collection of evidence so that they could evaluate the scene and send detectives and officers out more quickly to canvas and investigate outside of the immediate scene. Many have indicated the value of having the panoramic image available for a “walk-through” of a scene once it has been released, which extends from current and open cases to cold cases. Some agencies have adopted a panoramic imaging technology to reconstruct vehicular crashes and perform trajectory analysis, while others have found benefit in documenting fire and explosion scenes that have dark, sooty walls and items. Still other agencies have defined such utilities for the technology as corroborating witness and victim statements and documenting searches pursuant to a warrant. Some agencies have also described the further utility of being able to document such high-risk targets as schools and courthouses for homeland security purposes in their communities.

Panoramic imaging technology attempts to address the challenges and limitations that occur with traditional crime scene documentation, including the potential for disturbance or possible contamination of a crime scene; insufficient photo quality and organization; heightened expectation for investigative technology generated by the cultural "CSI Effect;"[16] and the need for more time to document and process a large or highly unusual scene.

Using panoramic imaging technologies, the quality and organization of scene documentation can be enhanced by providing a fluid navigation through a high-resolution scan with traditional pictures embedded into the panorama. This feature provides a technologically advanced exhibit for the courtroom and may enable juries to better understand the features of a crime scene and the reconstruction of events. In addition, depending on the adoption policy for the technology, a scanner's potential to document complicated and large scenes more quickly can lead to improved collection rates for transient and sensitive evidence. Finally, scanning technology can also provide the ability to tour, analyze, and reconstruct a scene long after the original documentation phase. Scanning technology, in effect, provides a spatially relevant "long-term memory" of the investigation scene.

2.2 Technologies/Products Selected for Evaluation

Many types of panoramic imaging technologies are available, covering a spectrum of capabilities and costs. They range from software-only products that allow the user to develop a panoramic image from digital photographs, to hardware and software combinations that capture and process data for a panorama, to hardware and software that measure the evidence at the same time as the image is captured. Three panoramic imaging technologies were selected to illustrate the spectrum of products available and marketed for forensic science purposes: SceneVision-Panorama, Panoscan MK-3, and the Leica ScanStation C10 (***Exhibit 1***).

It is important to note that the evaluated technologies are not the only ones available for panoramic imaging for scene documentation and that the inclusion of these three systems in the evaluation should not be considered an endorsement. Furthermore, these three technologies were not evaluated in a side-by-side comparison to determine which technology performs best; rather, this evaluation focused on the features and functions specific to each system to illustrate the spectrum of capabilities that this technology provides agencies. As a result, agencies should use the evaluation's results based on their specific needs, operations, and fiscal requirements when determining the type of system they require. Below is a brief description of each panoramic imaging technology selected for this evaluation.

Exhibit 1. Spectrum of complexity and cost of panoramic imaging technologies used in crime scene investigation.

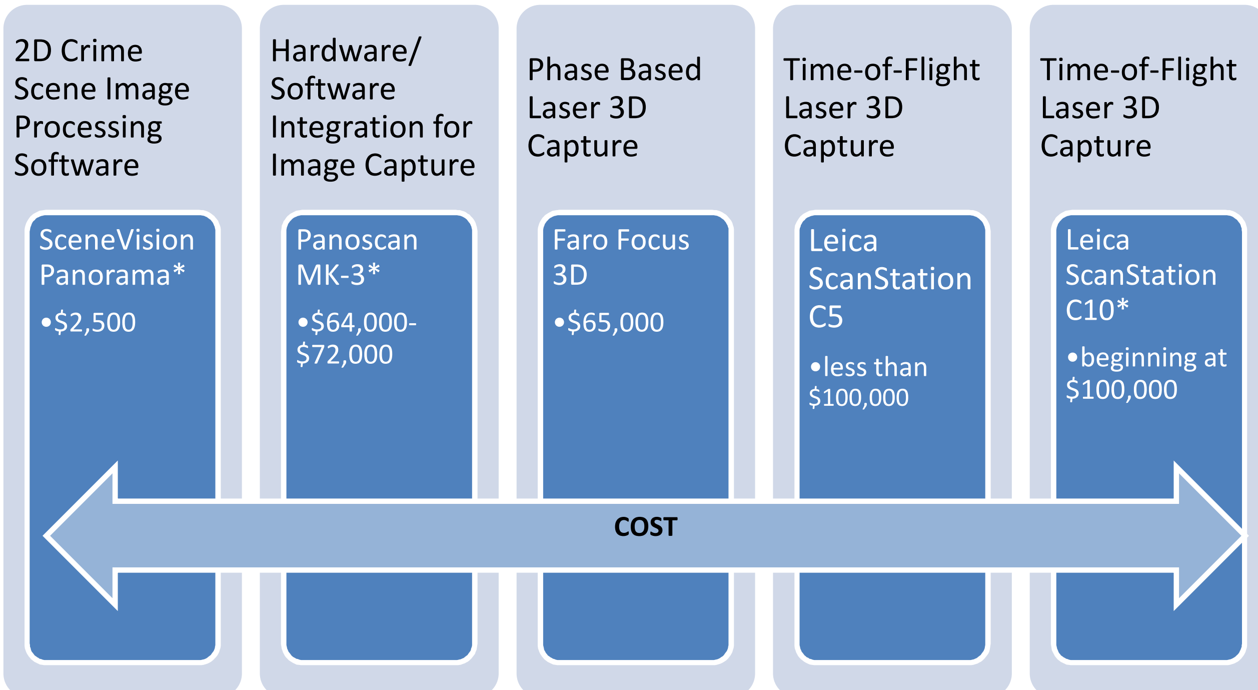

Figure note: Costs were approximated as of June 2013. Technologies listed in each category are examples of products in the category, and the (*) indicates a technology selected for FTCoE evaluation.

2.2.1 SceneVision-Panorama

A primary component of the SceneVision-Panorama system is software that uses 2D photographs to generate a virtual tour. SceneVision-Panorama stitches together multiple digital images to create a high-resolution panoramic image. The software allows panoramas to be viewed alongside diagrams of the scene, and panoramas can be linked together to simulate a virtual walk-through of a scene. In order to achieve the panoramic output, the camera must be mounted on a panoramic tripod head to prevent distortion of the final image. In addition, evidence measurements must be completed using traditional tape measures. Still photographs of specific evidence and measurements can be linked to the virtual tour and selected when additional detail is desired. A completely programmed tour can also be prepared and executed from a compact disc.

2.2.2 Panoscan MK-3

The Panoscan MK-3 is a specialized camera that creates a panoramic image during a 360° camera rotation. Unlike the SceneVision-Panorama system, this linear scanning technique does not stitch together numerous still images from an existing digital camera, but instead creates one fluid, 360° image using a standard lens. A fisheye lens can also be used for an increased vertical field of view. Multiple panoramic images can be linked to create a virtual tour, and still photographs of specific evidence can be embedded for reference when needed. The tour can be viewed as a virtual reality movie using movie players, such as QuickTime VR. As with SceneVision-Panorama, if using the MK-3,measurements of evidence must be completed using another piece of equipment, either a tape measure or another scanner.

2.2.3 Leica ScanStation C10

The Leica ScanStation C10 is substantially different from the SceneVision-Panorama and the Panoscan MK-3 systems. Although the SceneVision and Panoscan systems generate a single 2D panoramic image with links to midrange and close-up photographs, the Leica ScanStation C10 produces a truly 3D representation of the environment. The scanner projects laser beams across the environment and captures a wide vertical field of view while rotating 360^{o} along its horizontal axis. The scanner measures the distances and angles of the reflected laser beams and records the 3D coordinates in a point cloud. Using the recorded point clouds and environment photographs (taken by a camera built into the body of the scanner and collected simultaneously with the scan), the Leica scanner's software generates a 3D navigable model of the crime scene. Distances are calibrated using targets certified by the National Institute of Standards and Technology (NIST), thereby providing the ability to measure the entire scene without having to make traditional physical measurements.

2.3 Evaluation Overview

The purpose of this evaluation of panoramic imaging technologies is to provide an objective comparison of technologies used for crime scene documentation with the assistance of partnering law enforcement agencies who have already implemented one of the technologies into their agency's casework or operation. The SceneVision-Panorama, Panoscan MK-3, and the Leica ScanStation C10 systems are not specifically endorsed here-in, but were selected to represent the spectrum of scanning technologies currently marketed for crime scene documentation.

The specific technologies were selected based on the cost of the equipment and how much training was required to operate the equipment and process data. An additional consideration was to represent the spectrum of capabilities for panoramic imaging technologies. The sophistication of the equipment was considered based on the amount of technological expertise an operator would need to have to operate the technology and process the data with confidence. Operators were selected from local agencies that had adopted and implemented panoramic imaging technologies. The partnering agencies were The Virginia Forensic Science Academy; Roanoke and Arlington, VA Police Departments; and the Virginia State Police.

It is important to note that the technologies chosen for this evaluation are not the only ones available for panoramic imaging for scene documentation, and each vendor offers additional equipment systems. Each manufacturer offers an array of products at different price points with optional accessory packages. Also, these three technologies were not evaluated in a side-by-side comparison to determine which technology is good, better, or best. Rather, this evaluation focuses on the features and functions of the three types of equipment to illustrate the spectrum available to agencies.

2.3.1 Evaluation Team

The Department of Forensic Science at VCU partnered with the NIJ-funded FTCoE, led by RTI, to conduct the evaluation of panoramic imaging technologies used for crime scene documentation. VCU's Department of Forensic Science led the evaluation team, which was comprised of four Virginia-based law enforcement agencies. The following agencies were selected to participate in the evaluation as they had adopted one of the technologies selected for evaluation:

- Virginia Forensic Science Academy (SceneVision-Panorama)
- Arlington County Police Department (Panoscan)
- Roanoke Police Department (Panoscan)
- Virginia State Police (Leica ScanStation C10).

The information shared in this report represents the opinions of the individual practitioners and researchers who participated in the technology testing and evaluation, and not the opinions of their agencies or the NIJ. In addition, the individual agents were not part of the agency's technology selection process and have not participated in this project to endorse or protest any technology. No individual involved in the testing and evaluation process received any money or support from the manufacturers of the equipment. For more information or questions about the report, visit www.forensiccoe.org, e-mail ftcoe@vcu.edu, or call 804-828-8420.

2.3.2 Evaluation Design

The three panoramic imaging technologies were evaluated by VCU staff in an environment that simulated field operation conditions. To do this, both indoor and outdoor crime scenes were staged at Barrett Juvenile Correctional Center in Hanover County, VA, to compare each technology in a replicated field setting. The equipment operators from the partnering agencies were separately brought to the test site to document each scene according to their agency's respective protocols. Both mock crime scenes were designed to have the most natural light possible, finite barriers, and permanent points of reference.

The mock crime scene parameters are defined in ***Exhibit 2***. For each test, evidence was placed in the same location to eliminate potential bias. The evidence was also placed in a manner at the scene to make it challenging to the systems. After each test, the respective agency submitted the final exhibit prepared for each scene and answered a survey regarding the use and utility of the technology.

Exhibit 2. Evidence Used in the Outdoor and Indoor Mock Crime Scenes

Outdoor Scene Evidence		
Number	**Evidence Description**	**Notes**
1	Body—female with blunt force trauma	On right side to expose "injuries;" served as large item; minimum 4 feet from wall to corroborate castoff pattern on wall
2	Earring	On chest to discriminate layered and small item
3	Rifle	Long, slender item
4	Spent casing	Small item with color similarity to ground
5	Bowling pin (murder weapon)	Blood present—must be near body; hidden item
6	Wine glass	Transparent object
7	Pill vial	Item in victim's hand—hidden and layered object
8	Mirror with sugar	Reflective surface
9	Castoff bloodstain pattern on wall	Multidimensional item
Indoor Scene Evidence		
Number	**Evidence Description**	**Notes**
1	Body—male	Wound on neck—tape on body to indicate
2	Castoff bloodstain pattern on wall	Same evidence type, but present on different surfaces within the scene; served as multidimensional items, layered colors, and size challenges
3	Pool of blood under victim's head	
4	Arterial gush on wall	
5	Passive blood drops leading to table	
6	Contact transfer stain on axe from fingers	
7	Blood on axe	
8	Reflective mirror at window	Tested equipment's ability to document reflective surfaces, both the large window and mirror
9	Umbrella	Multiple bright colors on same object
10	Revolver on desk chair	Blue training revolver on blue chair (layered colors)
11	Keys on desk	Small item
12	White Styrofoam cups (2) on table	Light color on light color, movement

3. Findings

In this section, we provide results for each tested product for each of the evaluated variables. The first section discusses hardware/software, cost, and training, which are further summarized in Exhibit 2. We begin with hardware and then discuss set-up/calibration, data capture (including challenges), processing the data, and preparing the final presentation. A summary of the findings is presented in ***Exhibit 3***.

A more detailed, results-driven evaluation report is also avalilable on the FTCoE website, www.forensiccoe.org. This longer report provides more in-depth information for each of the evaluated imaging technologies, including graphics, photographs, and technical details.

Exhibit 3. Hardware, Cost, and Training of Evaluated Panoramic Imaging Systems*

Technology	Hardware Cost	Software Cost	Onsite Training
SceneVision-Panorama	Panoramic tripod head: $350 Camera, lens, and tripod: $1,000 Optional purchases (at additional cost): • fisheye lens	SceneVision-Panorama and PTGui: $1,500	None (a training manual is included with purchase)
Panoscan	MK3 System: • $64,000–$72,000, option dependent Includes: • Panoscan camera body • 80-gig processor module • 15-foot camera cable • 10-foot USB 2.0 cable • Daylight infrared, IR blocking filter • Battery and storage case • ViewFinder software Optional purchases (at additional cost): • Tungsten IR blocking filter • Gitzo tripod and leveling head • Additional Panoscan lenses • Laptop computer • LED lighting kit • Additional postproduction software • Panometric measurement device	Software included in package: • ImagePrep Optional software examples purchased from independent vendor to process images and convert into viewable formats (movies): • Pano2VR: $100 • Adobe Photoshop: $600	Not required, but advised • $5,000 for up to 5 people onsite for 2 days
Leica ScanStation C10	ScanStation C10: >$100,000↑, depending on options purchased. Includes: • 1-year warranty • Scanner body • Data collector (laptop and tablet) • NIST-traceable artifacts • Registration targets Optional purchases (at additional cost): • Additional hardware coverage plan ranging from $1,500–$10,000 annually	Software included in package: • Cyclone Optional purchases (at additional cost): • $3,000 annual software updates	Two 4-day classes for up to eight people are included as a line item in the purchase price More training is available for additional cost

*All information was provided by the partner agencies based on their experience in implementing the technology and is accurate as of June 2013.

NIST = National Institute of Standards and Technology

3.1 Hardware, Cost, and Training

Each technology has different hardware requirements for field operations. The SceneVision-Panorama is the least equipment-intensive, requiring only a panoramic tripod head to be added to a traditional photography kit. The tripod head, which attaches the device to the tripod, can be purchased through the vendor, 3rd Tech; however, any panoramic head may be used. The Panoscan system requires a tripod, the Panoscan camera, lenses, laptop computer, and cables to connect the various components. The Leica system requires a tripod, the C10 itself, batteries, registration targets (for measuring and point cloud stitching), and a computer.

The SceneVision-Panorama system requires almost no additional considerations for transportation. The Panoscan and Leica equipment systems are packed in multiple cases and, as a result, also require significant space in an equipment truck. Both the Panoscan and Leica units require batteries, although the participating agencies noted that they had not encountered any issues with battery life. The Leica C10 allows batteries to be swapped out while the unit is in use. Each system requires a single operator, although the Panoscan and Leica system evaluation teams noted that two to three team members are ideal to allow for faster activity logging, set up, and take down. Both Leica and Panoscan offer equipment warranties. Leica will also recalibrate the equipment as part of the warranty.

As shown above in Exhibit 3, all three panoramic imaging technologies have specific field hardware and processing software. All information was provided by the partner agencies based on their experience in implementing the technology and is accurate as of June 2013.

3.2 Set-up and Calibration

The first metric tested was the time required to set up and calibrate the equipment once on scene. SceneVision and Panoscan systems require approximately 5 minutes for set up, with the Leica ScanStation requiring closer to 10 minutes. Operators of the Leica ScanStation did note that set up time increases to closer to 15 minutes with a single operator.

The SceneVision system required a one-time, 10-minute calibration with the panoramic head prior to use to ensure image distortion did not occur while taking photographs. The Panoscan system required no calibration before use. The Leica ScanStation requires a minimum of one scan using the NIST-certified registration targets to verify measurement accuracy. This process takes roughly 5 minutes to perform, and multiple target scans at different locations can be made in the course of scanning the scene.

3.3 Data Capture

Once calibration is complete, data capture can proceed. The equipment operator must first assess the crime scene to determine if all pieces of evidence are in a direct line of sight from a single location. When using the SceneVision or Panoscan, if any piece of evidence is hidden from direct view of the technology, the operator must then decide whether additional scans from other locations within the scene are needed to capture all the evidence. If the evidence is not in a direct line of sight and the operator decides to take only one scan, the end product for Scene Vision and Panoscan is a virtual tour linked to still photographs to supplement the single scan. The Leica ScanStation requires scans from multiple locations to produce a complete 3D model of the environment; therefore, scanning locations for the ScanStation must be selected to optimize evidence capture. A complete 3D model of the environment may not always be necessary, and, as such, a ScanStation scan can also be supplemented with traditional still photographs.

The scan for SceneVision-Panorama is actually two series of photos from one location in the scene, each series being taken at a different angle. Each series of photos took a little more than 1 minute, resulting in 2 minutes total to scan the scene. The Panoscan requires two scans per location as well; the first scan, which lasted 8 minutes in the evaluation scenes, ensures that the scan is appropriate and anomaly-free. The second scan is used for actual data collection and took only 4 minutes. Total time for scene scan with Panoscan was, therefore, 12 minutes. The Leica system took approximately 25 minutes for each scan location in the scene. Nine locations were selected to scan from in the interior scene, and five locations were used for the exterior scene. Thus, the Leica ScanStation total time to scan and measure the scenes was 225 minutes for the interior scene and 125 minutes for the exterior scene. However, since the Leica ScanStation automatically captures evidence measurement data, no traditional physical measurements were recorded using a tape measure. To make a more accurate comparison with Leica ScanStation, evidence measurement time was recorded for both SceneVision and Panoscan. Comparatively, the ScanStation's time to scan is not excessively long (see ***Exhibit 4***).

Each system's resolution can be adjusted. SceneVision's resolution is adjusted using the settings on the camera used to take the photographs. The Panoscan and Leica systems' resolution can be specified prior to each scan. While the resolution setting for the digital camera (for SceneVision-Panorama) and the Panoscan does not impact the scan time for each technology, a higher-resolution setting for Leica can increase the scan time. Thus, an agency would need to balance the resolution needs, especially for a complex crime scene, with scan time. Ultimately, the additional time necessary for the Leica ScanStation may not be an issue since the time needed to document a complex crime scene by traditional methods would conceivably also take much longer.

3.4 Image Capture Limitations

The same limitations and interferences that traditional documentation techniques have are also applicable to these systems. For example, movement during image capture can result in blurring with both the SceneVision and Panoscan systems, while the Leica system is prone to "ghost images."

Light availability affects all three systems differently. SceneVision requires carefully selected exposure times on the camera for a series of photographs. The Panoscan system has an optional lighting kit that can attach to the tripod; however, the agency that had implemented Panoscan noted that the ambient light was usually sufficient for a scan, unless the crime scene was at nighttime with poor ambient lighting. While poor lighting affects the image quality for the Leica ScanStation C10, the laser scan feature has no problems taking distance measurements for the point cloud in poor lighting.

Capturing images in bright sky or bright light conditions can result in uneven exposure if part of the scene has less light than others. As a result, areas of the resulting image will appear excessively brighter than other areas. Each system has features to compensate for this issue. SceneVision allows photographs to be taken at varied shutter speeds and aperture settings to accommodate the light and dark areas. Panoscan can have multiple scans processed using image processing software, such as Adobe Photoshop, to resolve the variability. Finally, image smoothing software with the Leica ScanStation can be used to resolve uneven exposures.

As with any imaging technique, reflective surfaces may cause the scanning equipment's reflection to be present in the final product. In addition, the Leica ScanStation has some trouble integrating point cloud data of some reflective surfaces, like water or shiny black surfaces, and will generate a dark area in the end product.

3.5 Software Requirements and Processing

The SceneVision system required 5 hours total to stitch together individual photographs using the PTGui software and to develop the panoramic images for both crime scenes. Links between the panoramas and still photography were then added to complete the virtual tour, and overview diagrams were added. The operators did not develop diagrams with measured evidence, but this would have added an additional 4–5 hours to develop the diagrams and then link them to the panorama.

Although the panoramic images taken by the Panoscan were immediately available following the scanning process, it required approximately 1 hour to add links to still images using the Pano2VR software. The additional 4 hours to process the data (as seen in Exhibit 3) is a result of measurements generated from the Total Station System, which is a Leica product that measures points of interest without using a tape measure. The operators of the Panoscan then hot-linked these diagrams with measurement data into the final panorama. The Leica

ScanStation C10 took about 4 hours to produce the 3D virtual environment, which included the digital evidence measurements collected at the time of the scan.

3.6 Presentation Preparation

The final scene presentation generated by each of these technologies can be viewed from almost any computer with a modern Windows operating system. The SceneVision final presentation required 5 hours total to prepare for both interior and exterior scenes and consisted of a 360^{o} stitched panoramic photograph with embedded links to still photographs. The Panoscan final product was also a 360^{o} image with embedded links to still photographs, which required approximately 1 hour to develop.

The Leica ScanStation final product is a true 360^{o} 3D image with embedded links to still photographs and interactive evidence measurements. This product required approximately 4 hours to develop. However, depending on the complexity of the scene and nature of the end product, the ScanStation could take up to 8 hours to develop. SceneVision Panorama and Leica ScanStation have software that allows animation, with zooming and field-of-view control, while the Panoscan system does not allow animation.

3.7 Summary of Findings

Exhibit 4 provides an overview of findings for the three evaluated panoramic technologies. Reported findings include general consideration (hardware/equipment, transport, personnel requirements, third-party support); instrument calibration and image capture; and interferences.

Exhibit 4. Overview of Findings From Evaluation

General	SceneVision-Panorama	Panoscan	Leica ScanStation C10
Hardware/equipment	Panoramic head	Tripod, scan unit, lenses, computer, batteries, accessories	Tripod, scan unit, targets, computer, batteries, accessories
Transport	Small addition to traditional photo kit	Large hard-side case, soft carry case	Multiple large hard-side cases
Personnel requirements	1	1–2	1–3
Third-party support	Panoramic heads, stitching software	Image processing software	No
CALIBRATION/CAPTURE			
Setup time	3 minutes	10 minutes	10–15 minutes
Calibration	One-time, 10-minute setup	N/A	NIST calibration during target acquisition, approximately 5 minutes
Time on indoor site	135 minutes*	155 minutes*	225 minutes**
Time on outdoor site	90 minutes*	125 minutes*	125 minutes**
Scans (indoor)	Two scans, average of 1 minute each	Two scans, average of 6 minutes each	Nine scans, average of 25 minutes each
Scans (outdoor)	Two scans, average of 1 minute each	Two scans, average of 4 minutes each	Five scans, average of 25 minutes each
INTERFERENCES			
Weather	No known issues outside of normal camera operation	No known issues outside of normal camera operation	May need environmental case for freezing weather
Low light	Challenging to develop an evenly lit panorama	Longer scan time without lighting kit	Camera functions affected, measurement capabilities unaffected
Movement	Generates blurring	Generates blurring	Generates ghost images
Skies	Featureless skies can result in challenging stitching	Glare, hot spotting	Bright skies can result in uneven exposure
Reflections	Equipment may be in scan	Equipment may be in scan	Reflective surfaces may appear dark/blacked out
Featureless surfaces	May be necessary to include known reference point	May be necessary to include known reference point	No known issues

(continued)

Exhibit 4. Overview of Findings From Evaluation (continued)

General	SceneVision-Panorama	Panoscan	Leica ScanStation C10
SOFTWARE			
Processing time	5 hours total***	5 hours total	4 hours
Preparation	Stitching images into panorama, hotlinking still photography and overall sketches	Hotlinking still photography, developing Total Station measurement diagrams	Evidence selected to show measurements, assembling virtual tour
File size (Raw + distributable)	0.638 GB	2.85 GB	6.63 GB
Final product	Panoramic images with links to still photography, animated virtual tour using panoramas and stills	Panoramic image with links to still photography	3D virtual tour capable of some interactive measurements and links to still photography

*includes measuring evidence with conventional tape measure; ** measurements were made by the ScanStation C10; *** processing did not include developing diagrams from hand-measurements. Would take another 4–5 hours to develop these diagrams.

4. Conclusions and Recommendations

Findings from this evaluation show that all three of the panoramic imaging technologies that were evaluated add distinct and tangible short-term and long-term value to criminal investigations.

Each of the technologies provide law enforcement personnel the ability to create more authentic representations of a crime scene when compared to conventional still photography and videography because of the added ability to virtually “walk through” a crime scene, as well as to develop multiple viewer perspectives.

Panoramic imaging can make documenting a crime scene more objective since an investigator would not necessarily have to decide what aspects of the crime scene to prioritize during the initial stages of an investigation. Instead, the entire scene can be documented during the initial investigation for later review. This approach allows evidence or items that are otherwise unremarkable to still be documented, unlike standard documentation protocol in which an item may be overlooked.

Scanning technologies also offer the ability for an agency to reenter a crime scene via a “virtual tour” occurring days, weeks, months, or years after it has been released. This benefit could be helpful in situations like cold cases where an investigator is not likely able to tour the original crime scene.

Ultimately, the capability to digitally reenter a scene and to reanalyze, reinterpret, and reconstruct events is an asset measured by a users' ability to create more efficient, effective, and compelling exhibits for communication, which can improve all aspects of a criminal investigation. Before an agency adopts this technology, they must define their purpose and goals for using panoramic imaging technology. The agency should evaluate the predominant types and frequencies of cases it manages and the role of technology in those cases. The agency should also determine the value of using a scanning technology to complement other agency technology needs to justify the expenditure and efforts toward implementation.

Furthermore, an agency must develop realistic expectations about the technology's functionality since none of these technologies will fully replace all documentation practices at a scene and may not be necessarily appropriate to deploy in every scenario. Panoramic imaging capability will never completely supersede or replace traditional, manual methods for crime scene processing. Once a technology is purchased, the capabilities and limitations of the equipment should be documented and understood and standard operating procedures written to provide guidance to the operator to make the appropriate decisions at a scene.

Agencies also need to ensure that operators of the equipment are appropriately trained to make certain they will be able to competently operate the equipment and process the data. Even for systems such as the SceneVision Panorama that are less complex in their design, the operator needs a strong foundation in photography theory. In addition, the skill set for using these systems degrades if not used regularly.

A critical consideration for purchase must be an agency's level of commitment to supporting equipment, dependent upon their defined needs and purposes. Some technologies have long menus of optional accessories and require significant space for storage and transportation (for instance, some agencies have created "scanning teams" to commit vehicles and people). Equipment manufacturers also rapidly re-develop different aspects of these technologies, so an agency should consider the commitment to hardware and software upgrades when deciding to adopt. An agency should also consider purchasing a warranty to protect their investment; this is specifically true for the ScanStation C10 re-calibration, which is included as a part of the warranty.

Agencies also need to formulate a plan for how the resulting data will be archived, shared, and processed. Panoramic imaging technologies require secure storage that can accommodate original and processed images originating from either high-resolution images or millions of data points collected on scene. These images should be treated the same as any other crime scene digital photographs, with appropriate protocols for use. We highly recommend that any agency adopting scanning technology follow the best practices and guidelines set forth by the Scientific Working Group for Imaging Technology (SWGIT) for the capture, storage, processing, analysis, transmission, output of image, and archiving of data.[20]

Once an agency has worked through all these decisions and defined their capabilities and commitments, they can fully assess the strengths and weaknesses, functions, and characteristics of each technology to determine the most appropriate purchase (***Exhibit 5***).

Exhibit 5. Strengths and Weaknesses of Evaluated Panoramic Imaging Equipment

	SceneVision-Panorama	Panoscan MK-3	Leica ScanStation C10
Strengths	• Cost-effective • Single agent operation possible • Crime scene units will already have most of the hardware • No special transport considerations • Easy to learn and use • Fast to deploy on scene • Third-party stitching software can be used	• Data collection is "push button" • Single agent operation possible • Images are produced quickly on scene with minimal processing • Excellent photo quality • Few transport considerations • Third-party software can be used • No stitching is required	• Measures large areas much faster than manually • Data-rich scene capture; millions of points measured • Unit can make measurements even when ambient light is too low for photography • Unit is weather resistant • Every element in the scene is measured • Removes operator bias from measurement
Weaknesses	• No automation • Operator must have strong basis of photography theory and photo composition • Scan times can take longer in low-light conditions because of photography requirements • Non-descript rooms or featureless open areas are difficult to stitch • Especially large scene files can tax older computers	• Auxiliary light sources must rotate around the camera or they will appear as a starburst • Light source is sold separately, but is needed for low-light environments • Uneven lighting at scene requires additional software processing • Panometric photogrammetry system is inaccurate outside of 25 feet (not evaluated for this report) • Training is separate from purchase • High-resolution pictures can tax older computers	• Slower than manually measuring for tight and small scenes • Comprehensive measurement times are greatly increased by clutter/debris/obstructions • Must have clear line of sight to document elements in scene • Requires training commitment • Not user friendly • Equipment is bulky and requires transport considerations • Large file size • Computer knowledge is a requirement to use and perform backend processing

The final recommendations of this evaluation are as follows:

1. Panoramic imaging technology should not be purchased to replace all existing documentation methods and general SOPs in crime scene, fire, and crash investigation units. While specific elements of current SOPs may become unnecessary with the adoption of a scanning technology, the technologies are meant to be a valuable complement and augmentation to existing documentation methods. Therefore, the technology should align with the needs of the department.

2. As with all techniques and equipment that are applied to forensic investigations, it is important to determine to what degree these applications are reliable and

valid and how they can be implemented most effectively. Expectations and scope of use in the field and in the courtroom should be defined, with flexibility for an operator to make appropriate decisions in a given scenario and an understanding as to a technology's limitations. Agencies should evaluate these elements to develop optimized crime scene protocols and conduct adequate training.

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