A Technical Evaluation of Three Panoramic Crime Scene Imaging Technologies

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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, the FTCoE, 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. Finally, no individual involved in the testing and evaluation process received any financial or materials support from the manufacturers of the equipment. For more information or questions about this report, visit www.forensiccoe.org, e-mail ftcoe@vcu.edu, or call 804-828-8420.

1. INTRODUCTION

Digital crime scene documentation has become an essential component in criminal investigations and the judicial process. In fact, two-dimensional (2D) and three-dimensional (3D) imaging technologies allow law enforcement personnel to skillfully create high-resolution, 360^{o} images or data. These panoramic imaging technologies enhance the quality and organization of crime scene documentation by providing fluid, high-resolution scans with embedded photographs. They also allow agencies to provide more detailed documentation of the crime scene and can increase an agency's ability to document more complex crime scenes and improve evidence collection rates. Further, digital documentation of a crime scene provides the ability to analyze and spatially reconstruct a scene past the initial documentation phase.

As with any technology, law enforcement agencies need objective information regarding the challenges and benefits of panoramic photographic imaging to adopt an appropriate technology. 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 digital crime scene documentation. The purpose of the evaluation was to objectively compare three different technologies to assess the capabilities, requirements, benefits, and challenges of each. The evaluation examined operational use and technical requirements (including ease of setup, system calibration and operation, technological capabilities in varying scenarios, processing, and final output); hardware and software needs; pricing; and training requirements. **Appendix A** outlines the steps an agency may consider taking when adopting and implementing a new technology into their casework processing.

The three technologies selected for evaluation were the SceneVision-Panorama by 3rd Tech; the MK-3 by Panoscan; and the ScanStation C10 by Leica Geostation. These technologies represent a spectrum of crime scene documentation. SceneVision-Panorama uses limited on-scene hardware and is designed to stitch together traditional photography into single panoramas. The Panoscan MK-3 is a unique rotating camera that records a complete panorama as a single image, which is made immediately available post-scan. The Leica ScanStation C10 system also records a full panorama, as well as collects millions of data points using a time-of-flight, three-dimensional (3D) laser scanner to provide a computerized representation of the crime scene. All three technologies are capable of producing a navigable virtual environment, while the Leica can produce a navigable 3D environment.

This report will discuss the specific results of the evaluation and considerations that an agency should make when deliberating the adoption of a panoramic imaging technology. An executive summary report titled, *Technical Advances in the Visual Documentation of Crime Scenes: An Overview, which* includes prior research, the history of panoramic imaging technologies in criminal investigations, and recommendations for selecting a technology can be found on the FTCoE website (www.forensiccoe.org).

2. BACKGROUND

2.1 Prior Evaluations

Panoramic imaging technologies have been used widely in other fields. These fields have tested and validated these technologies, explored their strengths and limitations, and indicated their potential value for use by law enforcement. However, to date, a formal evaluation, comparison, or hypothesis-driven experiment of panoramic imaging technologies as they apply to the documentation and analysis of routine or selected types of crime scenes could not be found in traditionally peer-reviewed literature.

Published recommendations for the use of panoramic scanning technologies were limited to anecdotal experiences of unusual crime scenes.

An overview of prior research and evaluations, including references to specific studies and system development history, can be found in the *Technical Advances in the Visual Documentation of Crime Scenes: An Overview* report located on the FTCoE website. Manufacturer contact information is summarized in **Table B-1** of **Appendix B**.

An Evolution of Panoramic Imaging Technologies in Forensics

For more than a century, the criminal investigation process has relied on the documentation of crime scene images as an essential tool. The evolution of photography from black and white media to digital images has brought greater efficiencies to this process. Further, the advent of user-friendly imaging software has led to an exploration of the benefits of "stringing together" photographs to create panoramic images. Given the value of such spatial documentation, panoramic imaging technology that has been used in other industries has made its way into use for criminal and civil investigations.

Ultimately, panoramic imaging technologies complement traditional crime scene documentation techniques by comprehensively and efficiently recording high-resolution, 360^{o} images. These technologies have been used for the pre-collection crime scene evaluation, post-release evaluation of crime scenes, development of more compelling courtroom exhibits, and property and security management. Crime scene scanners have shown the potential to significantly enhance the documentation of large or complicated crime scenes, as well as to improve documentation organization by creating a spatially relevant and navigable visual record. Using panoramic data capture to allow for a "virtual" walk through of a crime scene long after it has been processed can be invaluable for investigators, judges, and juries.

2.2 Technology System Overview

A brief description of the selected panoramic imaging technologies are provided. These descriptions include its basic operation, major components, and application.

2.2.1 3rd Tech: 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. Unlike still photographs, the panoramic images allow the evidence to be spatially represented within the context of the scene environment. 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^{o} 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^{o} 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.

Table 1 offers example crime scene evaluation products along the spectrum of complexity and cost. The list is not exhaustive of available products but is presented to illustrate the kinds of products by way of a few examples. The items marked with an asterisk (*) were selected for evaluation.

Table 1. Example Products for Visual Documentation of Crime Scenes*

2D Crime Scene Image Management Software	
SceneVision Panorama* http://www.3rdtech.com/SceneVision-Panorama-specs.htm	Software that stitches together 2D photographs to generate a high-resolution panoramic image. The software can simulate a virtual walk-through of a scene using the panoramic output; however measurements are slightly distorted and must be completed using traditional methods. ~$1500.
Photomodeler www.photomodeler.com	Software that extracts measurements from multiple still 2D photographs using geometric algorithms based on focal length, lens distortion, relative positions, and camera angles. $1,200-2,500.
Hardware and Software for Image Capture and Manipulation	
Deltasphere 3000 http://www.deltasphere.com/	Combines a 3D Scene Digitizer with a digital camera and uses positioning motors, computer controllers, and computer graphics software to take thousands of measurements per second to capture a 3D model of the scene. Combined with 2D high-resolution, digital color images captured by a professional camera, the SceneVision software creates a 3D color model.
iSM http://is.mdacorporation.com	Mapping and modeling systems developed for lunar landscape that are offered for forensics. Products include MDA's CBRN Crime Scene Modeler - a multi-sensor 3D mapping system designed to support the investigation of crime scenes contaminated with Chemical, Biological, Radiological, and Nuclear (CBRN) agents.
PanoScan MK-3* http://www.crime-photo.com/	Specialized camera creates a single 360^{o} panoramic image using a standard lens. The linear scanning produces one fluid image rather than stitching together numerous still images. ~$45K.
PanoScan PanoMetric http://www.panoscan.com/PanoMetric/	Two panoramic images are scanned using a special tripod, and then processed to ensure geometric accuracy. When loaded into PanoMetric software for measurements, pixels in the scene accurately portray distance and special data. Once PanoMetric collects the results, CAD programs can be used for 3D modeling.
SceneWorks www.spheron.com	Visual scene documentation and management – the entire SceneWorks package includes use of SceneCam (full spherical camera system to capture the scene) and SceneCenter (database solution to manage, process, and document a scene). Together, the SceneWorks package allows clients to connect 3D photogrammetric measurements and spherical imagery and produce a visual interface of crime scenes. Available through www.csimapping.com.
Laser Technologies for 3D Image Capture	
Surphaser 3D Laser Scanners www.surphaser.com	Portable 3D laser scanners with sub-millimeter accuracy with scan rate of up to 1.2 million points per second designed to operate in industrial or outdoor environments. Surphaser software allows data sets to export into 3D modeling packages.
FastScan 3D www.polhemus.com	Handheld wand projects a fan of laser light onto an object, while the camera instantly views the laser feedback, sending the cross-sectional depth profiles to a computer to automatically stitch the scans together, producing the real-time visual feedback as 3D images. ~$10K.
Focus 3D Laser Scanner www.faro.com	High-speed Terrestrial Laser Scanner (TLS) for 3D measurement and 3D image documentation. 3D laser scanner produces dense point clouds that combine to produce detailed 3D color images. Multiple scans from different points can be combined.
"Total Station" Packages for 3D Imaging	
ILRIS-3D www.optech.ca	Product integrates digital image capture and software tools for accident scene reconstruction. Digital images are captured using ground-based LIDAR scanners to collect and evaluate 3D image data. ~$100K.
Leica ScanStation C10* http://hds.leica-geosystems.com/	Scanner projects laser beams across the environment and measures distances and angles of the laser beam reflections to produce 3D images of a scene. Packages start at ~$100k.
Riegl vz-400 www.reigl.com	Uses a narrow infrared laser beam and fast scanning mechanism to deliver high speed, highly accurate, non-contact data acquisition. ~$160K.
SX Robotic Total Station www.sokkia.com	Advanced laser measurement and image processing within the station. Also includes tracking, turning, and angle accuracy using the Sokkia software. Available through www.csimapping.com.

*These technologies were evaluated and further details are in the report narrative.

3. METHODS

3.1 Evaluation Team

The VCU Department of Forensic Science at VCU partnered with the FTCoE (RTI International) to conduct the evaluation of panoramic imaging technologies used for crime scene documentation. VCU's Department of Forensic Science coordinated the evaluation team, which was comprised of four Virginia-based law enforcement agencies (see team contact information in **Table B-2** of **Appendix B**). Two practitioner agencies were used for the Panoscan evaluation: an experienced team (+5 years) with an older model and a less experienced user with a newer model. These agencies were selected for participation because they had adopted and implemented one of the technologies selected for evaluation into their agency's casework or operations:

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

3.2 Evaluation Categories

To provide an objective comparison of crime scene imaging technologies, VCU partnered with four law enforcement agencies to evaluate three scanning technologies—the SceneVision-Panorama, the Panoscan MK-3, and the Leica ScanStation C10. These scanning technologies are not specifically endorsed, but represent the spectrum of scanning technologies currently marketed for crime scene documentation. Cost, training, and technology sophistication (for example, the amount of technological expertise required to operate the equipment and process data) were considered to describe the range of the spectrum.

It is important to note that the technologies chosen for evaluation are not the only ones available for panoramic documentation of crime scenes, nor are they the only equipment systems offered by each vendor. Each manufacturer offers an array of products at different price points, with optional accessory packages. This evaluation focused on the characteristics and functions of the three types of imaging technologies and does not attempt to rank their capabilities in relation to others. The evaluation focused on the evaluating the following six performance categories for each technology: Hardware, Cost, and Training; Set-up and Calibration; Data Capture; Image Capture; Software Requirements and Processing; and Presentation Preparation.

VCU staff evaluated the imaging technologies in an environment that simulated field operation conditions. Two mock crime scenes, one indoor and one outdoor, were staged at the test site at Barrett Juvenile Correctional Center in Hanover County, VA, to compare each technology in a reproducible field setting. The mock crime scene parameters are defined in **Table 2**. The equipment operators from each of the partnering law enforcement agencies were separately brought to the test site to document each scene according to their agency's respective protocols and to develop a final product (i.e., exhibit) for use in the courtroom.

Table 2. Evidence Used in Mock Crime Scenes

Number	Evidence Description	Notes
Outdoor Scene Evidence		
1	Body- female with blunt force trauma	On right side to expose "injuries," 4 feet from wall to corroborate castoff pattern on wall
2	Earring	On chest to test small item discrimination
3	Rifle	Long, narrow item
4	Spent cartridge case	Small item with color similarity to ground
5	Bowling pin	Blood present, behind trash can
6	Wine glass	Transparent item
7	Pill vial	Item held in victim's hand- hidden, layered under fingers
8	Mirror with confectioner's 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 on wall	Similar evidence types, but present on different surfaces within the scene. 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 blade of axe	
8	Mirror leaned against window	Reflective surfaces, both the large window and mirror
9	Multicolor umbrella	Multiple bright colors on irregularly shaped object
10	Revolver on desk chair	Blue training revolver on blue chair as color contrast challenge
11	Keys on desk	Small item
12	White Styrofoam cups (2) on table	Light colored items, moving due to air flow

Both mock crime scenes were designed to maximize the amount of natural light present and to provide finite barriers and permanent points of reference. Evidence was placed in a manner that challenged certain aspects of the documentation systems, and evidence placement was identical for each test to eliminate potential bias. After each test, the agencies submitted the final exhibit prepared for each mock crime scene.

3.3 Technology Assessment Tool

Following the mock crime scene evaluation and submission of a law enforcement agency's resulting final exhibit, VCU staff surveyed each agency to gauge the implementation and utility of the imaging technologies. The assessment addressed the technology's ease of set-up, calibration, operation for data collection, capabilities in certain scenarios, software processing, and preparation of the final exhibit. Information regarding hardware and software requirements, pricing, and training commitments was also collected.

The following sections outline specific components and processes for the technologies that were addressed in the evaluation and assessment. The questions presented were meant to objectively and thoroughly address issues that were considered critical for any agency during pre-adoption research.

3.3.1 Hardware, Cost, and Training

Operational conditions at a crime scene vary greatly. Confined spaces may not allow for pieces of large hardware to be used. A source of power for the scanner itself and additional light sources may not always be available on-scene. Each of the three technologies has a different set of hardware required for use, which affects the variety of considerations. Questions regarding a technology's hardware requirements included the following:

- What does transport entail? Are there special considerations?
- Can the technology be operated without electricity? Does it require batteries?
- How many people are needed to operate the equipment?
- Are there special storage considerations?

3.3.2 Set-up and Calibration

To determine the operational capabilities of imaging technologies, the evaluation reviewed the impact of technology set-up and calibration on the documentation process. Long set-up and calibration times require an on-scene benefit analysis for creating a panoramic image and may result in an inability to document transient evidence. Fundamentally, each scanning technology functions differently (only one of the technologies measures items during data collection) and, therefore, employs vastly different calibration protocols. When calibration is required, completion off-site prior to deployment, when possible, decreases the time it takes to for a technology to become operational at the crime scene. Proper calibrations are necessary to prevent artifact-laden final products and/or inaccurate measurements. To assess set-up and calibration, system operators were asked the following:

- How long does it take to set-up the equipment?
- Does equipment require on-site calibration?
- How long does calibration take?
- Is calibration NIST traceable?

3.3.3 Data Capture

High-resolution and high-quality final products require a longer data collection period. Because documentation must be completed quickly to allow investigators to collect and preserve evidence, perform on-site tests, and clear obstructed public access ways, the time required for the scanning technology to collect data should be considered and understood before incorporating a new technology into existing protocols.

Each agency was asked to use the scanning technology to fully process the mock crime scene to include measuring the evidence and taking traditional still photographs, if necessary. To achieve this task, the system operators pulled tape measures and took traditional photographs with the SceneVision-Panorama and Panoscan MK-3 technologies. The following questions were applied to the data capture process:

- How many scans does it take to capture all evidence items?
- Is it necessary to capture all items of evidence with this equipment?
- How long does it take to document and measure all the evidence on the scene?
- What types of evidence are difficult to capture with this technology?
- What parts of the environment are difficult to capture?

Image Capture Variation in substrate qualities (e.g., diffuse vs. specular reflection, textured vs. smooth surfaces) and environmental conditions (e.g., lighting amount and type, smoke or fog, movement) can affect the final product of each of the imaging technologies, particularly with regard to image quality. Features of these technologies may render them more capable in one type of environment than another. Technology limitations in regards to image capture were assessed by the following set of questions:

- Are some surfaces more difficult to document than others?
- Is the technology more suitable for indoor or outdoor scenes?
- Does variation in lighting affect the scan?
- Are there problems with capturing movement?
- Are there problems capturing reflective surfaces?
- Do featureless surfaces cause problems with photo stitching?

3.3.4 Software Requirements and Processing

Each technology has different software requirements to transform the raw data into a final product that can be viewed as an exhibit. The complexity of the software depends on the technology and the level of detail required in the final product. For instance, links to traditional still photographs may be incorporated with SceneVision and Panoscan; however, with the Leica ScanStation, it may be unnecessary to manually incorporate photographs, depending on the end use of the system.

To create an acceptable final exhibit for the courtroom, several factors may impact the quality of the product, including the type of software needed, system requirements, processing time, and training. The following questions were used to address system software requirements and processing:

- What software is required? Is it technology specific?
- Are there multiple types of software available?
- What are the system requirements for the equipment’s processing software?
- How long does it take to process the scan into a finished product?
- What is the final product’s file format? Is it proprietary?
- How large is the final product’s file size?
- Is training required? Is it available?

3.3.5 Presentation Preparation

The purpose of the final exhibit determines how an agency will prepare and process the data for presentation. For example, providing a jury with scene walk-throughs requires a highly automated presentation that will highlight items of evidence, while an investigator performing a virtual walk-through may want a high degree of manual control with regard to panorama zoom and rotation and will need to see all elements in the scene. Each technology uses a different method for final product presentation, and options exist for different final products. Agencies the following questions about presentation preparation:

- What is the best presentation method with this technology?
- How long does it take to develop those materials?
- Is animation possible?

4. FINDINGS

4.1 Summary of Findings

In this section, we provide results for the three evaluated panoramic imaging technologies, broken out by category (Hardware, Cost, and Training; Set-up and Calibration; Data Capture; Image

Capture; Software Requirements and Processing; and Presentation Preparation). A summary of the assessment findings are provided in **Table 3.**

Table 3. 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
SOFTWARE			
PROCESSING TIME	5 hours total***	5 hours total	4 hours
PREPARATION	Stitching images into panorama, hot linking still photography and overall sketches	Hot linking 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.

4.2 Hardware, Cost, and Training

Each technology has its own 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 special considerations for transportation. The Panoscan and Leica equipment systems are packed in multiple cases and, as a result, require additional, if not 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 adverse 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 recommend two to three team members 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 in **Table 4**, the hardware and software requirements for each technology impact cost and training. The SceneVision-Panorama was the least expensive and least complicated system evaluated. As such, it had available the least amount of training; however, significantly less training was actually required to become operational with this technology. Panoscan is a mid-level entry into scanning technology and requires moderate training investment for its unique camera system and software. The Leica ScanStation C10 was the most expensive technology evaluated, with the highest technological sophistication, but was also the highest-functioning technology.

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

Table 4. 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: • $40,000–$45,000, option dependent (without training) 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

4.3 Set-up and Calibration

The first metric tested in the technology evaluation was the time required to set-up and calibrate the equipment once on scene. The SceneVision and Panoscan systems require approximately 5 minutes for set-up, while the Leica ScanStation requires 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 requires a one-time, 10-minute calibration of the panoramic head prior to use to ensure that image distortion does not occur while taking photographs. The Panoscan system requires 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.

4.4 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 evidence is hidden from direct view of the technology, the operator must 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 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 takes only 4 minutes. The 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 the interior scene, and five locations were used from 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 additional time was spent recording traditional physical measurements. 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 was not excessively long (see **Table 3**).

Each system's resolution can be adjusted. SceneVision's resolution is adjusted via 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 have to balance the resolution preferences, 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 take much longer.

4.5 Image Capture

The same limitations and interferences that affect traditional documentation techniques are also concerns with 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 each of the 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 a crime scene has less light, which cause some areas of the panoramic image to appear excessively bright in comparison to 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 allows multiple scans to be processed using imaging software, such as Adobe Photoshop, to resolve the variability. The image smoothing software of 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. 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.

When using a scanning technology to document an interior scene versus an exterior scene, hardware size must be considered. Since SceneVision-Panorama requires no additional hardware other than a tripod head attachment, the tripod footprint when scanning is no different than for traditional photography using a tripod. For indoor use of the Panoscan MK-3 and Leica ScanStation C10, the size of the room must adequately accommodate the tripod and equipment. Small rooms may create a "barrel effect" for Panoscan, and the ScanStation may be cumbersome in tight quarters with the targets, but this challenge can be overcome for each technology.

Large, featureless environments pose a challenge for the SceneVision and Panoscan systems, as they interfere with image processing and the stitching together of images. The vendor recommendation is to affix a small sticker in the nondescript regions of the space to create a point to identify an edge for the stitching. Environmental conditions may cause minor difficulty with all three systems; high humidity can cause lens fogging; and freezing temperatures may require the Leica ScanStation to warm up prior to use. The ideal conditions for image capture with all three scanners are the same: even lighting and as little movement as possible.

In the mock crime scene evaluations, all three technologies had difficulties capturing two particular items of evidence: a brass cartridge case in a patch of brown grass, and a small bloodstain on a brick wall. Both of these are small items on similarly colored backgrounds and had to be captured with still photography.

4.6 Software Requirements and Processing

The SceneVision system required a total of 5 hours 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 added to complete the virtual tour. Overview diagrams were also added. The operators did not develop diagrams with measured evidence, but this would have added an additional 4 to 5 hours to develop the diagrams and 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. An additional 4 hours were required to process (as seen in **Table 3**) 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 hot-linked these diagrams into the final panorama with the measurement data. 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.

Software requirements also vary with each system. SceneVision-Panorama software relies on the use of image stitching software; PTGui or another third-party image stitching software. Both SceneVision-Panorama software and PTGui require approximately 850MB of hard drive space on a computer with Windows XP or later. Files for SceneVision are stored in high-resolution.jpg format. Storing images in lower resolution will reduce the file size of a completed product. Viewing the end product requires SceneVision software, although the final product can be run from a CD without software installation. The SceneVision software is user-friendly and does not require training to use effectively; however, a training manual is included with the technology's purchase.

The Panoscan system comes with a laptop that meets software system requirements. ImagePrep software is included with the technology's purchase to process data collected from the MK-3 and prepare it for developing the movie. Software options used to process images and create movies for this system include programs such as Adobe Photoshop, Pano2VR, Vista FX, and VRWorks. Some Panoscan models allow wireless data transfer to the laptop, while others require a flash drive or optical disc. The completed product for a crime scene similar to the mock scenes, including two panoramas and links to still photography, will have a file size of approximately 100MB. Panoscan can be opened with Internet Explorer but does not require internet access. The software is user friendly, but requires hands-on time to establish familiarity. Training is available at additional cost, but is not required.

The Leica software requires training for use, and additional advanced training is available. This software is more technical than the software needed for Panoscan and SceneVision. Viewing the Leica final product requires the installment of a plug-in for Internet Explorer, while Cyclone software is required to view raw scan data. These file are typically smaller than 200MB for viewing in Internet Explorer and below 4GB for raw data. The raw data is stored as a.bin, while the distributable is stored as an.htm file. There are third parties who produce the point cloud processing software needed to handle raw data files. The data from the Leica ScanStation C10 can be wirelessly transferred to a laptop, but the Virginia State Police use DVDs to distribute results due to the large file size. The minimum requirements for software install are a 2 GHz dual core processor; 2GB of RAM for Windows XP or 4GB for Vista or Windows 7; 40GB hard disk space; and SVGA or OpenGL accelerated graphics card. Leica Geosystems provides a laptop that meets these specifications with purchase.

4.7 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 the Leica ScanStation have software that allows animation, with zooming and field-of-view control, while the Panoscan system does not support animation.

5. EVALUATION IMAGES

Figures C-1 through C-12 present images from the SceneVision-Panorama, Panoscan, and Leica ScanStation C10 taken for this evaluation. A description of each of the images and features within the images is included.

6. CONCLUSIONS AND RECOMMENDATIONS

Findings from this evaluation, as presented in **Table 3**, show that all three of the panoramic imaging technologies add distinct and tangible short-term and long-term value to criminal investigations. The strengths and weaknesses of each system are summarized in **Table 5**.

Table 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 25ft. (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

Agencies should be able to evaluate their specific needs, operations, and fiscal boundaries to make an informed decision as to the most appropriate equipment to purchase. This evaluation is an example of the research an agency should perform to discover what technology best suits their needs and the requisite resources.

Since the vendors of the technologies are significant sources of information and support, a strong recommendation is to have the vendors perform demonstrations on site in both simple and complex scenarios that are relevant to the agency. While it might be most beneficial to have the vendors on site at the same time, this may not be possible. Thus, having the vendors perform on-site demonstrations within a short timeframe is highly recommended.

6.1 System-Specific Conclusions

6.1.1 3rd Tech: SceneVision-Panorama

The SceneVision-Panorama system by 3rd Tech is meant to augment existing documentation capabilities. The animated virtual tour provides context and spatial orientation for traditional still photographs and serves as a tool to organize those photographs. It is an inexpensive system that requires little to no new equipment, depending on an agency's current photography capabilities. SceneVision-Panorama also requires minimal training (using the included manual), depending on an agency's technological competency, and would require only modest protocol modifications for implementation.

6.1.2 Panoscan: MK-3

The Panoscan MK-3 system provides high photographic quality and some advanced documentation options and is moderately priced. Formal training by the vendor is highly recommended to fully implement and use all features of the system. Technical assistance is available after training. This system can easily be implemented by an agency to complement existing documentation techniques with minor changes to existing documentation protocols.

6.1.3 Leica Geosystems: ScanStation C10

The Leica ScanStation C10 is the most advanced of the technologies, delivering a final product that includes NIST-certified measurement capability and true 360^{o} navigable imaging. While the photographic image generated is not high quality, the true panoramic image provides additional benefits and the measurement capability provides value by reducing the chances of contaminating sensitive evidence and improving measurement accuracy. It also allows the user to decide after a scene is released if any additional measurements would be beneficial and to make those measurements from the point cloud in the final product. In the end, the Leica ScanStation C10 requires the highest financial commitment to purchase and extensive training to adopt. It would also require the most extensive documentation protocol re-development because it can replace conventional measuring techniques.

6.2 Adoption Recommendations

An agency must consider many factors in the purchase and implementation of new technology, from fiscal resources and personnel competencies to the ability to commit to training requirements. The agency should also evaluate the predominant types and frequencies of cases it must manage and determine the value of using a scanning technology for other applications used by the agency, such as mapping communities and high risk targets. The additional uses may help justify the expenditure and efforts toward implementation. Alongside this internal survey, it is recommended that agencies reach out to other agencies who have successfully implemented a technology to gather information on the range of users, applications, and types of technologies before making a purchase.

Considerations for Adoption

- Define agency needs
  - Develop realistic expectations
- Determine purpose of technology use
  - Standard Operating Procedures
- Commit to training and continuing education
  - Evaluate potential operator expertise
- Acquire appropriate supporting equipment
  - Space, transportation, accessories
  - Software upgrades, repairs/calibration
  - Dedicated hardware and associated upgrades
  - Manufacturer warranty and maintenance plan
- Allocate secure storage for data archiving
  - Procedure for maintaining original data
  - Establish shared data practices
  - Documentation of image processing

It is highly recommended that regular intra-agency trainings are performed to maintain and advance operator (i.e., officer) competencies for any of the technologies, but most importantly, for the most technologically advanced instrument. It is also highly recommended that the adoption of any scanning technology follows best practices and guidelines as set forth by the SWGIT for the capture, storage, processing, analysis, transmission, image output, and archiving of data.[3] More information on adopting a new technology can be found in **Appendix A**.

Crime scene documentation is already a data-intensive enterprise, but the addition of high-resolution images or 3D renderings can greatly increase the hard disk drive space required for each case file. For the two small mock crime scenes documented in this evaluation, file sizes varied between 0.6 GB and 6.7 GB. These space requirements can be dramatically increased if enhancement techniques are used on such large images. Additional secure file storage solutions may be a necessary purchase if new panoramic imaging technologies are expected to be used on a regular basis. Large file sizes can be reduced with compression, but the potential effects on data quality should be carefully considered.[2]

Other adoption considerations will vary by department, but must include the methods for running departmental validations prior to deploying a new technology under field conditions. Internal validation, i.e., an accumulation of test data to determine whether established procedures perform as expected with reproducible results, is needed to ensure the functionality of new equipment and address courtroom concerns.[4] Comprehensive validations are a necessity and will also reduce the risks of on-scene complications. These validations should not be limited to hardware performance because software behavior may not remain consistent when used on different operating systems.[5]

The recommendation of this evaluation is that these technologies should not be purchased to take the place of all existing documentation protocols in crime scene, fire, and/or crash investigation units. With this said, some elements of current protocols may become unnecessary with the adoption of one of these scanning technologies. Either way, any of these technologies are a valuable complement and augmentation to existing documentation methods. Ultimately, the capability to digitally reenter a scene and to reanalyze, reinterpret, and reconstruct events is an asset measured by a user's ability to create more efficient, effective, and compelling exhibits for communication, which can improve all aspects of a criminal investigation.

7. REFERENCES

[1] E. Rogers, *Diffusion of Innovations, 5th ed.*, New York, New York: The Free Press, 2003.

[2] Scientific Working Group on Imaging Technology. (2010). *Staying current in digital imaging technologies: considerations for managers*. Available from: http://www.crime-scene-investigator.net/swgit-section2.pdf.

[3] Scientific Working Group on Imaging Technology. (2010). *Use of imaging technology in the criminal justice system.* Available from: https://www.swgit.org/pdf/Section%201%20Overview%20of%20SWGIT%20and%20the%20Use%20of%20Imaging%20Technology%20in%20the%20Criminal%20Justice%20System?docID=35

[4] Scientific Working Group on DNA Analysis Methods. (2012). *Validation guidelines for DNA analysis methods.* Available from: http://swgdam.org/SWGDAM_Validation_Guidelines_APPROVED_Dec_2012.pdf.

[5] Scientific Working Group on Digital Evidence (2009). *SWGDE Recommended Guidelines for Validation Testing.* Available from: https://www.swgde.org/documents/Current%20Documents/2009-01-15%20SWGDE%20Recommendations%20for%20Validation%20Testing%20Version%20v1.1.

APPENDIX A. ADOPTING A NEW TECHNOLOGY

Technology adoption and implementation can be a challenging task, even for a well-prepared law enforcement agency. In the scope of adopting a documentation tool, the urgent, yet time-intensive nature of crime scene documentation means that inserting a new element into an existing documentation protocol can affect the execution timeline of all other procedures. In addition, the threat of on-scene complications with a new technique decreases the certainty of a successful outcome and may exist even if end-users are familiar with a technology.

> A technology usually has two components: (1) a hardware aspect, consisting of the tool that embodies the technology as a material or physical object, and (2) a software aspect, consisting of the information base for the tool [1].

In order to minimize challenges in the implementation of a new technology, agencies must invest significant time prior to purchase to evaluate technologies that have relevant trials demonstrating the spectrum of operation, from simple to complicated. They also must build a functional knowledge base for technology competency, strengthened with regular and frequent training sessions to foster appropriate implementation and use.

Finding a strong support network prior to adoption—such as manufacturer customer service, user-group forums, or face-to-face support—is one of the best ways to understand a product's history and remain abreast of product and industry updates. A broad support network can also provide insight to the operational and functional spectrum of technologies. Accounts of adoption and implementation from end-users with a variety of capabilities can offer a fuller understanding of the range of a technology, whether it involves a simple, minimally disruptive process with a low time commitment, or a more complex product that provides entirely new functionality, yet comes with large time commitments and substantial learning requirements. Other end users can also provide critical data regarding their own cost-benefit analyses and make suggestions to overcome gaps that could challenge the full adoption and implementation of a technology. Information related to the underlying principles of how equipment functions is not necessary for adoption, but is highly recommended, as comprehending technology fundamentals prior to system trials and adoption reduces the chances for misuse, underutilization, or discontinuance of purchased technologies [1].

Supporting the operator with frequent opportunities to employ perishable skills and use a technology's more complicated features post adoption is of chief importance [2]. Not all companies provide training as part of the equipment purchase and, depending on the complexity of the product, advanced training may not be offered. Furthermore, it is likely to take less time to train a user to proficiency using a device's hardware than to train the same user to proficiency with data processing software. As a result, an agency must be willing to commit time, effort, and resources to ensure that operators become proficient users and maintain and advance their competency in using the technology's hardware and software.

Although there is no universal solution for adopting a new panoramic imaging technology, consideration of the following four general characteristics of adoption will better inform an agency during the adoption process:

- Relative Advantage – Whether the new technology makes existing processes easier, faster, cheaper, or adds new functionality.
- Complexity – The difficulty of understanding and using technology in the field, as well as the amount and type of training required for use.
- Trialability – The degree to which a new technology is available for use on a limited basis.

- Observability – The degree to which an adopted technology will produce visible results to those outside of the agency [1].

Other specific considerations should also be included in the cost-benefit analysis for justifying a new purchase. The Scientific Working Group on Imaging Technology (SWGIT) guidelines state that this analysis must include every step of the imaging workflow (i.e., data capture, transmission, storage, processing, archiving, and retrieval). The cost analysis should include a review of hardware, software, maintenance, security, training, facility upgrades, site preparation, staffing, and consumables. To prevent obsolescence, SWGIT notes that some agencies budget 15% of the original system cost annually for upgrades, training, and maintenance [2].

APPENDIX B. CONTACT INFORMATION

Table B-1. Evaluation Team Contact Information

Technology	Agency	Personnel
	Forensic Technology Center of Excellence, RTI International	www.forensiccoe.org forensicCOE@rti.org 866-2528415
	Virginia Commonwealth University, Department of Forensic Science	ftcoe@vcu.edu 804-828-8420
SceneVision-Panorama	Virginia Department of Forensic Science, Forensic Science Academy	Jeff Dwyer, Jeffrey.dwyer@dfs.virginia.gov 804-588-4144 Steve Stockman, Stephen.stockman@dfs.virginia.gov 804-588-4134
Panoscan MK-3	Arlington Police Department Roanoke Police Department	Marc Hackett , mhacke2@arlingtonva.us 571-334-2146 Keith Ahn, kahn@arlingtonva.us Chris Levering, Christopher.levering@roanokeva.gov 540-853-5817
Leica ScanStation C10	Virginia State Police, Appomattox	Kevin Harth, kevin.harth@vsp.virginia.gov 434-352-3443 Charles Myers, charles.myers@vsp.virginia.gov Clay Overholt, clay.overholt@vsp.virginia.gov

Table B-2. Manufacturer Information

Product Name	Manufacturer	Contact
SceneVision-Panorama	3rd Tech	http://www.3rdtech.com/SceneVision_Panorama.htm 929-361-2148 info@3rdtech.com
Panoscan MK-3	Panoscan	http://www.panoscan.com/MK3/index.html 818-990-1931 Online email form: http://www.panoscan.com/Challenge/Panoscan.html
Leica ScanStation C10	Leica Geosystems	http://www.leica-geosystems.us/en/Leica-ScanStation-C10_79411.htm 800-367-9453 or Technical Support 925-790-2325 support@lgshds.com

APPENDIX C. IMAGES FROM EVALUATION

Exhibit C-1 shows a view of the indoor scene taken with SceneVision-Panorama. This viewpoint can be rotated using the mouse to view the scene's entire panorama without changing zoom level. Three links are visible in this screenshot: the tripod symbol links to an additional panorama taken behind the desk; the yellow triangles link to up-close still photography; and the camera symbol links to a series of photos of the body. A diagram of the scene in the lower left allows navigation between panoramas, and a list of panoramas and photographs resides in the upper left corner.

Exhibit C-1. SceneVision-Panorama indoor view.

Exhibit C-2 is the entire panorama used for SceneVision-Panorama's indoor scene view, composed of two photographic series stitched together using PTGui. Each photographic series is composed of 12 individual photos, with the first series angled up to capture ceiling detail, and the second angled down to capture floor detail.

Exhibit C-2. SceneVision-Panorama indoor panorama.

Exhibit C-3 shows a SceneVision-Panorama view of the outdoor crime scene. This viewpoint can be rotated using the mouse in order to view the entire panorama of the scene without changing zoom level. Ten links are visible: the tripod symbol links to an additional panorama taken at a second location, the yellow triangles link to up-close still photography, and the camera symbol links to a series of photos of the body. A diagram of the scene in the lower left allows navigation between panoramas, and a list of panoramas and photographs resides in the upper left corner.

Exhibit C-3. SceneVision-Panorama outdoor view.

Exhibit C-4 is the entire panorama used for SceneVision-Panorama's outdoor scene view, composed of two photographic series stitched together using PTGui. Each photographic series is composed of 12 individual photos, with the first series angled up to capture roof detail, and the second angled down to capture ground detail.

Exhibit C-4. SceneVision-Panorama outdoor panorama.

Exhibit C-5 shows a view of the indoor scene captured with Panoscan using Internet Explorer. This viewpoint can be rotated with mouse controls to view the entire panorama without changing zoom level. The red circle links to another panoramic scan. Mousing over a specific item produces text with a description of the item (seen here as "Item #009"). Clicking on these links leads to traditional still photography. Panorama navigation is done by clicking and dragging the mouse or by clicking on the navigation buttons on the bottom center of the image.

Exhibit C-5. Panoscan indoor view.

Exhibit C-6 is the complete panorama used for figure 5, taken with a fisheye lens to capture ceiling and floor detail.

Exhibit C-6. Panoscan indoor panorama.

Exhibit C-7 captures a view of the outdoor scene captured with Panoscan using Internet Explorer. This viewpoint can be rotated with mouse controls to view the entire panorama without changing zoom level. Here the mouse is highlighting Item #001.

Exhibit C-7. Panoscan outdoor view.

Exhibit C-8 is the complete panorama used for Exhibit 7, taken with a standard lens. A fisheye lens was not used as the outdoor scene permits scanner placement that allows full scene capture with a standard lens.

Exhibit C-8. Panoscan outdoor panorama.

Exhibit C-9 captures a screenshot of the Leica TruView interface in Internet Explorer, with navigation tools on the right and measurement tools on the top toolbar. Navigation tools can be used to rotate the viewpoint, while the measurement tools can be used to measure the distance between any two points.

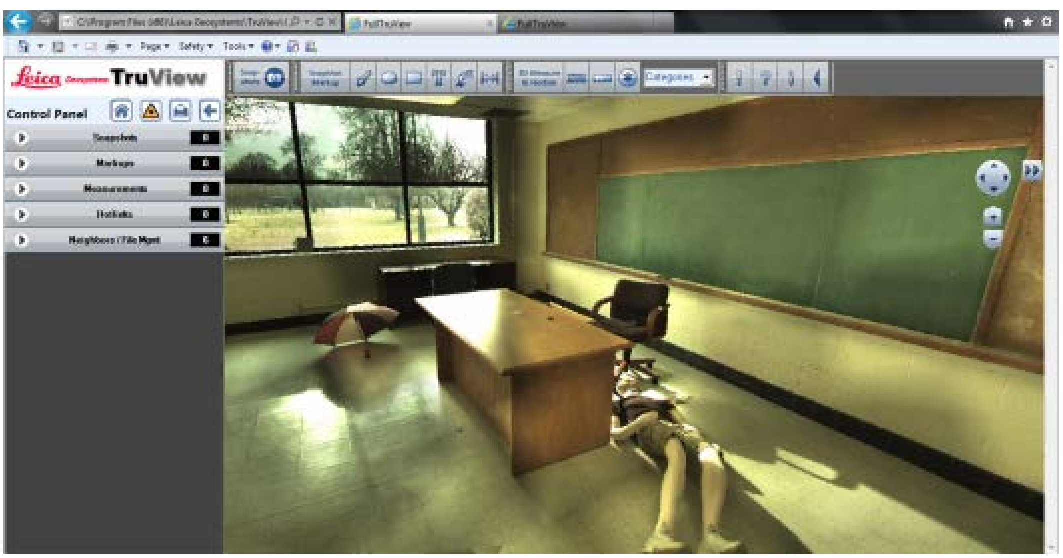

Exhibit C-9. Leica indoor view.

Exhibit C-10 presents a screenshot of integrated scans of the indoor scene taken with the Leica ScanStation C10. Unlike the SceneVision-Panorama and Panoscan systems, the Leica product is a 3D model of the scene. In this figure, each blue cross indicates an additional scan location, with the exception of three of the crosses which indicate registration targets. Registration targets will always be present in the rendering unless the scan is manipulated in some way.

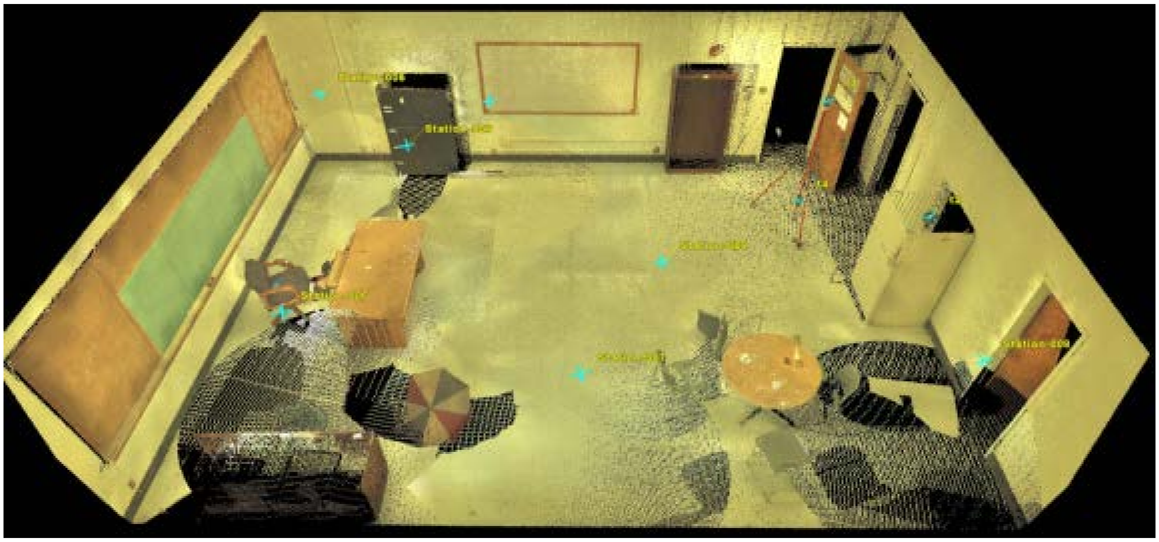

Exhibit C-10. Leica indoor integration.

Exhibit C-11 shows a screenshot of the outdoor scene with the Leica TruView interface in Internet Explorer, with navigation tools on the right and measurement tools on the top toolbar. Navigation tools can be used to rotate the viewpoint, while the measurement tools can be used to measure the distance between any two points. The yellow symbols link to other scan locations.

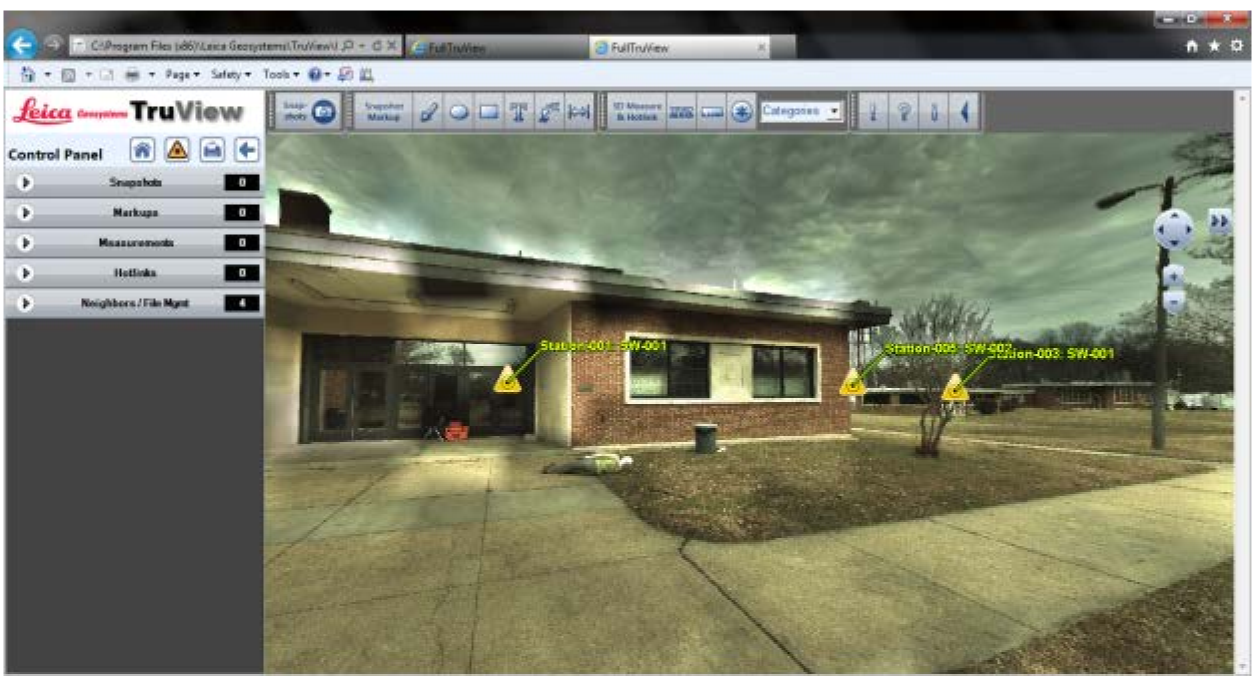

Exhibit C-11. Leica outdoor view.

Exhibit C-12 presents a screenshot of integrated scans of the outdoor scene taken with the Leica ScanStation C10. In this figure, each yellow symbol indicates an additional scan location. Registration targets are less visible in this orientation, but are still present unless the integrated scan data is manipulated in some way.

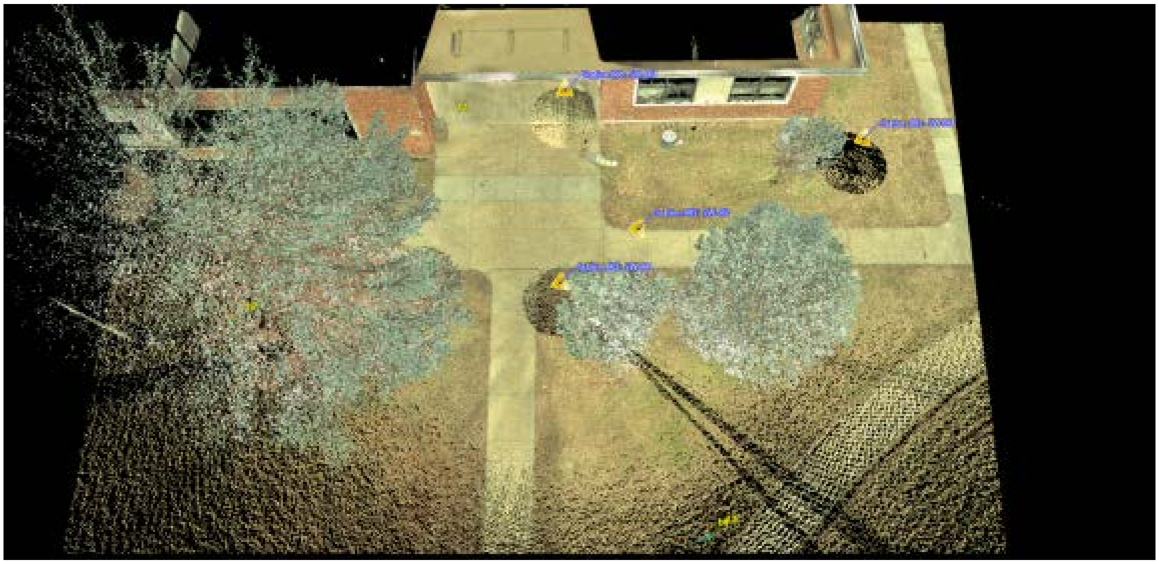

Exhibit C-12. Leica outdoor integration.