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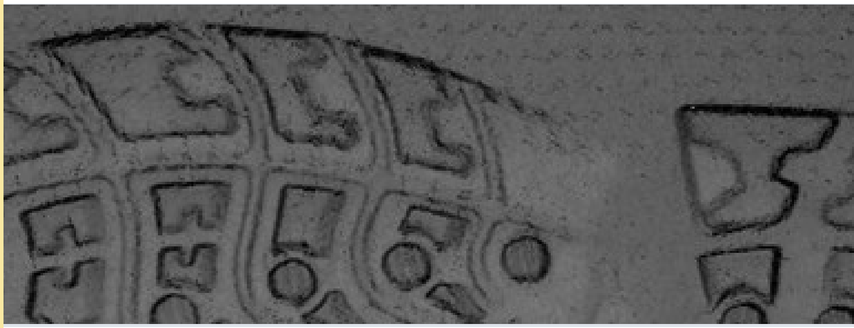
IN-BRIEF

Evaluation of Purdue University's 3D Imaging Prototype for Footwear and Tire Impressions



"We strive to develop a portable, affordable and easy-to-use high-end 3D scanner for the forensics community."

—Song Zhang, PhD, F. OSA, F. SPIE, Purdue University

Background

Three-dimensional (3D) impressions are created when a shoe or a tire encounters a malleable substrate, like soil or snow, and elements of the tread surfaces are reproduced in the substrate. This footwear and tire track impression evidence can link a person or a vehicle to a crime scene by providing investigative leads. Crime scene investigators (CSIs) capture impression details using two-dimensional (2D) photography and 3D casting techniques (e.g., dental stone casts), the quality of which often depends on the CSI's skill level, supplies, available time, and substrate type. Current photography techniques and casting methods require specific equipment, substantial time, and significant practice to properly execute, and success may vary based on substrate (e.g., high contrast soil, highly reflective snow). Casting techniques are inherently destructive, thus allowing one opportunity for collection. CSIs need additional methods that are quick, straightforward, affordable, and reliable enabling high-quality captures of the evidence.[1]

Key Takeaways

- Three-dimensional imaging systems for footwear and tire impressions may provide enhanced analytical capabilities for examiners.
- Training and experience in 3D software are recommended to fully engage the benefits of 3D imaging systems.
- Individual examiner preferences may vary regarding the use of the 3D scans versus traditional documentation methods.
- Practitioner feedback and recommendations are essential components of the testing, evaluation, and implementation process.

In March 2016, the National Institute of Standards and Technology's (NIST) Organization of Scientific Area Committees (OSAC) for Forensic Science issued a Research Needs Assessment detailing the need "…to test and validate 3D imaging technologies and associated products (used for both acquisition and output) for use in the recovery and examination of footwear/tire impression evidence."[1] The NIST report also determined that a major gap in current knowledge exists, and limited—if any—current research is being conducted to address it.[1] Then, in November 2018, the National Institute of Justice's (NIJ) Forensic Science Research and Development Technology Working Group (R&D TWG) identified the need for "improved evidence recognition, collection, and visualization tools and analytical instrumentation for field and lab use" for impression, pattern, and trace evidence.[2] Finally, in January 2021, the language of the OSAC Research Needs Assessment was updated to acknowledge that relevant research is currently being conducted but reiterated that a major gap in current knowledge still exists.[3]

3D Imaging Technology Under Review

Dr. Song Zhang and his research team at Purdue University led the development of a fully automated 3D imaging system, supported by two NIJ awards (2016-DN-BX-0189 and 2019-R2- CX-0069). The hardware was designed and manufactured by Orbbec 3D, and the algorithm and software were developed by VE Optics Inc. This system uses optical 3D scanning technology along with binary defocusing and auto-exposure control methods to capture a texture image (i.e., photograph) and develop a virtual 3D image of footwear and tire impressions.[4,5] The fully automated software algorithm and graphical user interface allow analysts to view the virtual impression as if they were studying it in situ.[5] The system converts the impression into a 3D rendering that can be rotated 360 degrees along any axis in the software and compared with a known source.[4]

In 2018, Dr. Zhang and his team introduced the 3D imaging system prototype to the forensic science community through conference workshops and compared it to commercial high-end 3D scanners and casting techniques.[4,5] In October 2020, they published their findings showing that their prototype achieved similar levels of accuracy and resolution as the high-end commercially available 3D scanner and offered greater affordability, ease of operation, and robustness.[4,5] In comparison to current casting techniques, the fully automated prototype "demonstrates its superiority because it (1) is non-destructive; (2) collects more evidence detail than casts, especially when an impression is fragile; (3) requires less time and money to collect each piece of evidence; and (4) results in a digital file that can easily be shared with other examiners."[5]

Evaluation Methodology

To address the research needs identified by NIJ R&D TWG and OSAC, the NIJ's Forensic Technology Center of Excellence (FTCoE) evaluated this prototype 3D imaging system's performance in a real-world setting with the assistance of footwear and tire examiners at three U.S. crime laboratories. The examiners were asked to provide their assessment on whether (1) the scanner was field ready, (2) the virtual impressions reproduced the footwear/tire evidence impressions accurately and precisely, (3) the 3D technology fits into examination processes and laboratory capabilities, and (4) they would purchase this technology in its current form.

This evaluation consisted of two phases, followed by interviews with each examiner. During phase one, the examiners used the scanner and software to create and visualize test impressions to gain familiarity with the 3D imaging system. Each examiner had access to PDF user manual documents provided by Dr. Zhang and attended a brief introductory meeting.

In phase two, the examiners compared evidence captured with the novel technology to evidence captured with traditional technologies (i.e., photographs and dental stone casts) by a certified CSI. The CSI created 3D footwear impressions in damp sand, dry sand, filler dirt and potting soil and 3D tire impressions in filler dirt and damp sand. The CSI scanned the impressions using the 3D scanner under various lighting conditions, scanner modes (e.g., High Dynamic Range [HDR]/non-HDR, low/high resolution) and with/without the use of a reference scale (see Exhibit 1). Impressions were then photographed using a Nikon D3500 digital camera with an 18–55 mm lens at varied focal lengths. Close-up photographs were taken in JPEG and RAW formats at 90° angles to the impression using a tripod. Dental stone casts of the footwear and tire impressions were produced from each type of medium.

Phase Two items submitted to examiners include the following:

- Known Source Items
  - Photographs of each source item, including upper and tread portions for footwear and tread design and sidewalls for tires.
  - 3D scans of each source item.
  - Transparent overlays, inked impressions on plain paper, and casts from BIO-FOAM® impressions for footwear source items.
  - Inked impressions on cardboard for tire source items.
- Questioned Items (five 3D footwear impressions and two 3D tire impressions)
  - Intermediate and close-up (examination quality) photographs of each impression.
  - Dental stone casts for each impression.
  - 3D scans of each impression using different scanner modes and by adjusting the physical conditions of the scan.

Examiner Feedback

Scanner Hardware

The evaluated scanner (approximately 11.7" × 7.7" × 6.7" without handles) was contained in a hard-shell ruggedized case with roller wheels and weighed approximately 33 lbs. (including contents). The case is large enough to fit all materials and durable enough to store and transport the scanner to a crime scene safely; however, the examiners noted that a smaller, lighter option would be better. For example, in jurisdictions with remote regions, crime scene personnel might have to travel long distances by van, airplane, or hike with limited storage space. In these situations, a smaller backpack version of the case would greatly increase portability. The scanner has attachable handles to transport the device outside of the case.

Impression Type	Scan Variables
Tire Impressions (2) Substrates: *Damp Sand & Filler Dirt*	**Lighting conditions:** *Natural, oblique, shade*
Footwear Impressions (5) Substrates: *Dry Sand, Damp Sand, Filler Dirt (2), & Potting Soil*	**Scanner modes:** *High Dynamic Range (HDR) or non-HDR* *Low Resolution or High Resolution*
	With and without use of a reference scale

Exhibit 1. Phase two impression type and scan variables.
Credit: FTCoE

In addition to the scanner, the case contained a fixing plate and four legs that attached to the plate with cotter pins creating a quadpod device holder. The scanner fits on top of the fixing plate and secures to the quadpod device holder with side clamps (see Exhibit 2). Multiple examiners cited concerns about the strength and stability of the quadpod device holder. Two out of three examiners felt the quadpod was too unstable or brittle to withstand repeated use by law enforcement and crime scene personnel, although one suggested the flexibility of the legs could potentially be beneficial in some terrains. During the evaluation period, several plastic clasps and strap attachments broke, requiring replacements.

Although examiners did not report any issues with the power system, they noted that the electricity requirement necessitated the use of extension cords to reach an outlet or proximity to an external power source, such as a crime scene van or a building. For remote crime scenes, this power requirement would be problematic. The examiners agreed that a battery pack option would be preferable, but some were willing to consider purchasing the scanner without it.

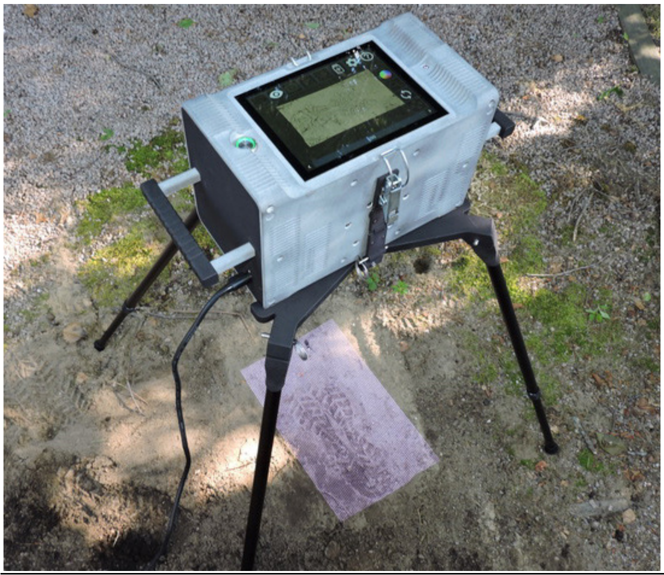


Exhibit 2. 3D scanner set-up to capture a footwear impression in soil.

Credit: FTCoE

The next iteration of the scanner prototype currently in development is smaller and lighter (approximately 6.9" × 6.7" × 6.7" without handles; see Exhibit 3) and is stored in a smaller case, which should address some travel and transportability concerns. Also, the developers have designed a new, more durable quadpod that provides stronger support for the scanner and is intended to be easier to use (see Exhibit 4). In place of the plastic clasps, the new quadpod uses strong magnetic attachments, allowing operators to move the scanner and quadpod as a single unit after set-up. In addition, battery power options are under development.

Scanner Interface and Ease of Operation

After capturing the image, the screen switches from the default "preview mode" to 3D view mode, which allows the viewer to see and adjust a 3D rendering of the impression before file transfer (see Exhibit 5). The touchscreen control window allows users to select options such as scan resolution (low/high), exposure time, HDR, and impression scaling, which includes rotation, zoom, and move options. When used in low-resolution mode, the camera's field of view is 7.9" × 14.0" at 140 dots per inch (dpi).[6] In high-resolution mode, the camera's field of view is 2.3" × 4.0" at 400 dpi. The time of capture for scans in high resolution takes slightly longer than low resolution; however, the time difference is negligible. Scanned images are captured as raw data .xyzm files to minimize storage space and are downloaded from the scanner via an external USB drive.

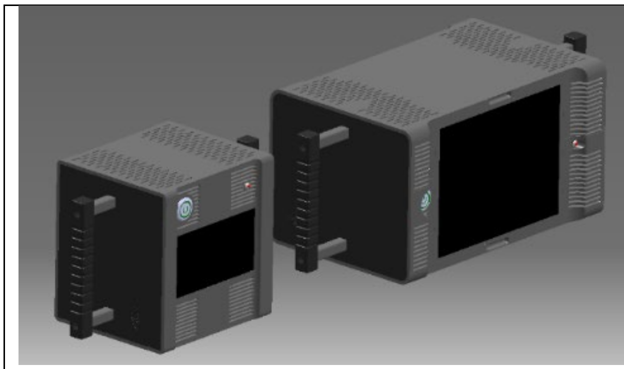


Exhibit 3. Scanner size comparison. The image shows the current model (right) and new prototype iteration (left).

Credit: Song Zhang, PhD

Exhibit 4. Side view of new tripod design.

Credit: Song Zhang, PhD

Exhibit 5. Overhead view of touchscreen interface with footwear scan on screen.

Credit: FTCoE

All examiners chose to reference the user manual to ensure proper usage of the scanner hardware but felt that they and their coworkers could operate the scanner with minimal instruction. Some felt that using the scanner was intuitive for those with camera skills or photography experience. Others felt the orientation of the scanner over an impression was contrary to traditional photography methods and needed additional time to master its positioning. During high-resolution scanning the field of view is limited and only a fraction of an impression can be captured requiring the scanner to be reset to capture the remaining areas. There was a degree of trial and error in adjusting the quadpod and scanner position to best capture the remaining areas. The examiners found this to be troublesome and were concerned that CSIs would fail to capture the entire impression, especially when documenting tire impressions.

The examiners had few, if any, issues with the touchscreen interface on the scanner. However, examiners noted that the high-resolution scans appeared distorted when previewed on the scanner screen. They did not have the same issue with the low-resolution images nor when viewing the files on a computer screen. This led to concerns about the scan quality that could not be immediately resolved at a scene. One examiner noted it was difficult to scroll through the menu or image view with the small scroll bar. Another examiner felt the overall screen and hardware orientation were opposite of what one would typically expect using a camera, making it somewhat counterintuitive to handle and maneuver over the impression. For example, a camera would normally capture a footwear impression parallel to the frame, but the scanner needed to be positioned perpendicular over an impression for capture. Additionally, for colder regions, one must consider limitations for those wearing gloves and their ability to use different touchscreen interfaces.

The next prototype currently in development has an upgraded touchscreen interface with multi-touch technology allowing users to zoom in and out more efficiently. The screen display is reoriented so that the movement on the screen matches the movement of the physical scanner. The screen display will be slightly smaller but ideally more user friendly for crime scene personnel. The updated version of the scanner has a file preview function so operators can verify the correct scans are selected for transfer to an external device and subsequent upload into the 3D viewing software. One feature under consideration for future iterations of the prototype is the ability to transfer data wirelessly from the scanner to a local computer in close range.

Software Installation

The scanner exports files in a condensed .xyzm format, and analysts require a downloadable viewer software (XYZT Viewer) to convert the files into standard mesh formats (e.g., STL, PLY) for use in most open-source 3D imaging software such as MeshLab and CloudCompare. Although the conversion process is simple and straightforward, it adds an extra step to the overall process. All examiners used MeshLab to view the scans; however, any 3D imaging software that accepts STL and PLY mesh formats can be used, allowing examiners to choose the appropriate software based on their need and comfort level. The XYZT Viewer is not currently compatible with Mac devices.

Crime laboratories regularly work with sensitive case material that requires stringent security. Many crime laboratories have firewalls that restrict what can be installed on devices in the network to protect against malware and other security threats. Downloading external software, such as the XYZT Viewer or MeshLab, often requires administrative approval and assistance from the Information Technology (IT) department. Laboratories looking to incorporate the scanner into their workflow may experience delays when trying to get the software installed and operational. All examiners experienced some level of difficulty during the installation process ranging from a day and a half to several days of troubleshooting with IT departments.

The examiners did not experience any major issues with the image files and were able to work with the file size, storage requirements, and transfer of data from the scanner to their laboratory computers. However, file loading times may vary depending on the number of scans, network capacity, and overall computing power.

The latest version of the prototype is now capable of exporting files directly in the standard STL or PLY formats. This allows analysts to bypass the installation of the XYZT Viewer for file conversion, streamlining the process and saving time, and to visualize files on both PC and Mac devices. Laboratories should still account for the storage requirements and upload timings of STL and PLY files for analysis, but many of the installation issues experienced by the examiners should be resolved in the updated system.

Software Ease of Use and Training

There is a learning curve associated with viewing and analyzing impression evidence in a 3D scan format. Familiarization with 3D visualization and an examiner's ability to navigate the software may require additional time and training. Examiners reported that they often needed to refer to the manual and watch tutorial videos before working with the software. Multiple examiners suggested that some test scan files and guided training on how to use the software would be beneficial to increase both user confidence and their ability to testify to their analyses using the software in the future. This training would allow users to gain proficiency with the software faster, reducing the learning time and facilitating implementation of the technology in casework. Examiners reported increased proficiency with the software as their examination periods progressed, which led to better outcomes and usability of scans. Although the examiners used MeshLab viewing software in the evaluation, some laboratories have started training their analysts using CloudCompare. Implementation of 3D footwear and tire impression analysis in laboratories might be more readily achieved when examiners already have training and experience using 3D imaging software.

Quality and Clarity of Scans

The examiners noted that depending on the size of the footwear impression, the low-resolution scan was able to capture the entire impression at once. It is unlikely the low-resolution scan would be able to capture a complete tire impression, but it may work for partial tire impressions similar in size to an average footwear impression. The examiners had differing opinions on the quality and utility of the low-resolution scans. One examiner preferred using the low-resolution scans to the high-resolution scans because of the ability to visualize the entire impression. The other examiners thought the clarity of the low-resolution scans was insufficient for comparison and analysis beyond class characteristics.

Overall, the examiners found the quality of the high-resolution scans to be equivalent to casts; in some cases, the scans provided more detail on logos and wear patterns. However, many noted that the small field of view was difficult to work with since only a small portion of the impression could be viewed at one time without additional contextual information. Examiners agreed that taking multiple scans and having the software stitch them together would likely produce scans of adequate size and quality for comparison purposes but would require crime scene technicians to carefully collect overlapping scans of the entire impression.

Multiple examiners felt that the scans lacked some contextual information that would be captured by casting and photography (e.g., debris in the shoe or impression such as a rock or leaf). One examiner preferred the 3D scans to traditional methods because of the maneuverability of the scan in 3D space through the software. This examiner felt the scans provided more information than 2D documentation methods, especially for the visualization of randomly acquired characteristics.

Financial Investment

The developers estimate the projected cost of the 3D imaging system to be just under $10,000. Traditional methods of documenting footwear/tire impression evidence use less expensive materials, but the examiners felt that this would be an appropriate price point for a 3D scanning device of this capacity. Examiners also expressed that if recommended improvements were implemented, it would be an item they would explore purchasing. One concern examiners noted was the limited amount of footwear evidence received in the laboratory despite the prevalence of impression evidence at scenes. Therefore, there would need to be a correlated increase in footwear/tire submissions from CSIs to warrant the projected price of the 3D imaging system.

Conclusion

> **"Of course, the hardware footprint will keep reducing, the software functions will keep increasing, and the system will become more refined. We believe this scanner has the potential to completely replace 2D camera for close-range evidence collection and documentation since we naturally capture 2D images besides 3D."**
>
> *—Song Zhang, PhD, F. OSA, F. SPIE, Purdue University*

End user feedback during technology development and evaluation helps create the best version of products to improve evidence collection and analysis. This 3D imaging system has undergone multiple reviews by different experts and practitioners who have provided their invaluable feedback.[5] Although the 3D imaging system has great potential, this evaluation by qualified footwear examiners has provided insight into additional adjustments and improvements, some of which are already under development, that may be needed before the system is ready to be commercially available for use in the field and incorporated into laboratory procedures. The examiners also provided insight into the overarching considerations laboratories and law enforcement agencies will need to weigh before purchasing and using the system, such as the applicability to their respective jurisdictions, need for training, and informational technology challenges. Each new version of the scanner hardware, accessories, and software improves upon the previous iteration, and the developers are actively working towards additional improvements in response to this most recent round of practitioner feedback before its public commercial launch.

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