IPNDV Working Group 3: Technical Challenges and Solutions
Chain of Custody (1)—Technology Data Sheet

September 16, 2016

Chain of Custody (CoC) Technology Name: 3D Facility Verification and Change Detection

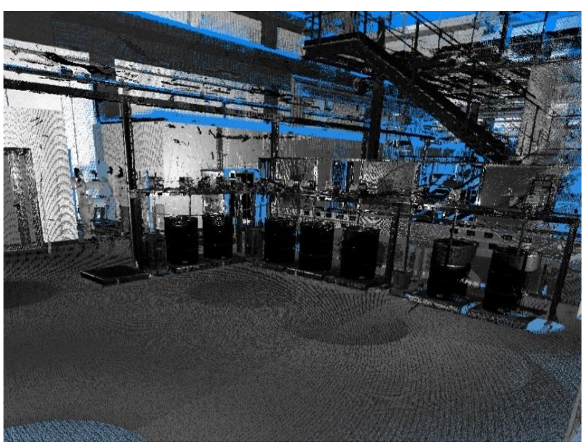
Physical Principle/Methodology of Technology:

Terrestrial 3D laser scanners and related processing software are used to create detailed and accurate 3D maps of the environment, e.g., a dismantlement facility or storage area. The 3D map can be used for verifying design information of a facility or it can be compared to previously acquired 3D maps, e.g., to verify that material containers have not been moved between inspections.

Time-of-flight laser scanners measure the distance to an object by emitting a laser pulse and measuring the time for the signal to be returned.[1] Alternatively, the laser signal can be modulated and the distance to the object is calculated from the phase difference between the returned signal and an internal reference signal (phase-based 3D scanner). Several hundred thousand single-point-measurements are taken each second. A full 3D image is acquired by using rotating mirrors. The sampling distance on the surface depends on the angular resolution that is selected and on the distance between the scanner and the surface. For example, an angular resolution of 0.05 degree corresponds to a sampling distance of 17 mm on a surface that is 20 m away from the scanner. The 3D scanners used for facility verification typically have a maximum measurement range of several hundred meters; the measurement accuracy is approximately 1 mm.

The scanners are mounted on a tripod and several images need to be acquired to capture the entire scene. After data acquisition, the 3D images are processed in dedicated software which has two main phases: first the individual 3D images (point clouds) are fused into a single 3D map, and then the data are analyzed according to the specific needs of the verification task. The analysis can be simple 3D measurements (distance, area, or volumes), comparison to available design information, or change analysis with respect to 3D maps that were acquired during a prior inspection (reference images). The processing provides additional information or highlights potential anomalies, which then need to be interpreted by the inspector, i.e., the inspector remains in charge of the final conclusion.

Figure 1 shows an example of applying 3D laser scanning to change analysis.



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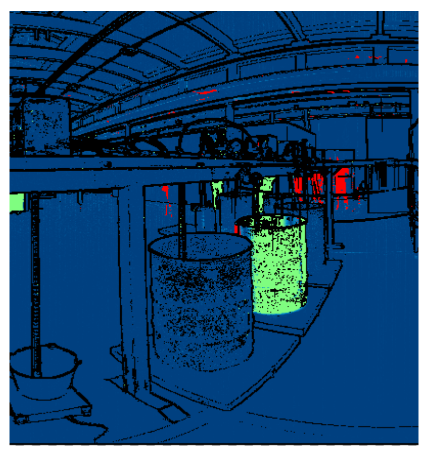

(2)

Figure 1: (1) snapshot of a 3D model of a (non-nuclear) facility; (2) change map generated by comparing the 3D model acquired before and after modifying the scene. Blue pixels correspond to unchanged

objects; red pixels correspond to objects that moved closer to the scan position or were inserted to the scene; green pixels correspond to objects that were moved away from the scan position or were removed. (Photo Credit: JRC)

Potential Monitoring Use Cases (pre-dismantlement, dismantlement, post-dismantlement, storage stage):

Facility Verification: 3D laser scanning could be performed during the entire dismantlement phase to verify the design information of the dismantlement facility with facility reviews and approvals. During the construction and before commissioning the facility, accurate 3D scanning is used to verify that the facility is being built according to the design information and does not contain any undeclared spaces or openings. After commissioning, periodic 3D scanning is used to verify that no undeclared modifications were made to the facility.

Containment and Chain of Custody: 3D laser scanning can be used to monitor access through perimeter areas in the different storage areas throughout the dismantlement phase. In particular, in can be used to detect (1) potential tampering with physical structures (i.e., open/closing of walls) and (2) undeclared movement of containers.

Physical Description of Technology (e.g., approximate size, weight):

Several 3D laser scanners are commercially available. They are typically mounted on tripods and weigh between 5 kg and 10 kg. Post-processing and data analysis is done on standard laptops or desktop PCs.

Time Constraints (e.g., measurement times, time to install the equipment):

Set Up Time: Advanced planning is required to get unoccluded views of features/objects of concern and overlap between successive images to allow proper registration to build the entire scene. The effort depends on the complexity and size of the facility.

Acquisition: A single scan takes about five minutes for setup and acquisition. The time for a complete acquisition campaign depends on the size and complexity of the facility that needs to be scanned. Typically, a single operator is able to capture an area of several hundred square meters per hour.

Processing: Data processing is carried out in a separate step. The basic post-processing for merging the scans into a single model is about one minute per scan. The time for data analysis depends on the type of analysis that needs to be carried out. The time for post-processing and analysis is approximately the same as the acquisition time.

Technology Complexity (e.g., hardware, software, and ease of use by personnel):

Acquisition: The operation of the 3D laser scanners is straightforward and basically limited to pressing the button for starting the scan. The acquisition locations and parameters should be planned properly in order to facilitate the later processing and maximize the quality of the resulting map.

Processing: The complexity of data processing depends on the software tool that is used and on the analysis that needs to be carried out. JRC's 3D Laser Verification System (3DLVS), which is focused on nuclear safeguards applications, was designed as an easy-to-use software tool for inspectors that are

[1] "LIDAR," available at https://en.wikipedia.org/wiki/Lidar.

not experts in 3D data processing. JRC offers a three-day course that trains for both data acquisition and processing.

Infrastructure Requirements (e.g., electrical, liquid nitrogen, etc.):

No specific infrastructure is required for data acquisition and analysis: the 3D scanners are portable and battery-powered. Processing is done on a standard laptop. However, a host might place specific restrictions on the equipment. For instance, a battery-operated laptop might be preferable to the host. Having multiple battery packs allows continuous operation by swapping depleted battery packs with freshly charged battery packs. The laptop and software will require host security review and then sanitization after use, to ensure that sensitive information has not been collected and removed from the facility.

Technology Limitations (e.g., detection limits for nuclear material, operational temperature range):

The measurement accuracy of laser ranger scanners is approximately 1 mm and any changes that are below that threshold will not be detected. For example, a container that was temporarily removed and later placed at the same position with an accuracy better than 1 mm will not be highlighted as changed.

Information Collected by the Technology (used to help determine if an information barrier is required for use):

3D geometry of the facility and its contents with an accuracy of approximately 1 mm. All processing and analysis can be done on-site, i.e., no item design information needs to be revealed and no information/data needs to be taken off-site.

Safety, Security, Deployment Concerns:

The only potential safety concern is the laser light emitted by the 3D scanners. However, most commercial scanners work with low-power lasers and are therefore classified as eye-safe. The laptop and software will require host security review and then sanitization after use, to ensure that sensitive information has not been collected and removed from the facility. The data might be stored on site between inspections in order to comply with information security constraints.

Technology Development Stage (e.g., commercially available, development stage):

3D laser scanners are commercially available. The processing software is developed by JRC and is operationally used in the field by Euratom and IAEA safeguards inspectors.

Cost Estimate:

The cost of 3D scanners and associated software is between €50,000 and €100,000 per laser scanner.

Additional System Functionality (e.g., outside the monitoring use case):

Mobile, real-time 3D laser scanners are now becoming available. They allow carrying out change analysis and design information verification more efficiently, however with a reduced resolution and accuracy. Additionally, mobile laser scanners facilitate efficient 3D mapping and provide indoor localization information to the inspector, thus enabling location-tagging of other measurements (e.g., radiation measurement).[2]

Where/How the Technology Is Currently Used (e.g., international safeguards, border protection):

3D laser scanning is used in a wide range of applications where accurate 3D measurements are required, including construction industry.

In the field of international safeguards, 3D laser scanning has been used by IAEA and Euratom for several years for verifying the design information provided by the operator and for verifying the absence of undeclared changes. Examples include DIV at the reprocessing facility in Rokkasho/Japan;[3] monitoring the storage of depleted uranium at Pierrelatte/France;[4] verification at the plutonium store in Sellafield/UK;[5] and verification of design information at the underground repository for spent fuel in ONKALO, Finland. Both IAEA and Euratom use the 3DLVS software for data processing and analysis, which was developed by JRC specifically for nuclear safeguards applications.

Examples of Equipment:

Several 3D laser scanners are available commercially. Figure 2 shows two examples of commercially available scanners and Figure 3 shows a snapshot of the 3DLVS software used by IAEA and Euratom for nuclear safeguards applications.

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Figure 2: Two examples of commercially available 3D laser scanners: (1) Z+F Iamger 5010C[6] and (2) FARO Focus 3D[7]. (Photo Credit: ZF, Faro)

[2] E. Wolfart et al., "Mobile Laser Scanning for Nuclear Safeguards," *ESARDA Bulletin* 53 (December 2015): 62–72.
[3] E. Agboraw et al., "IAEA Experience Using the 3-Dimensional Laser Range Finder," in *IAEA Safeguards Symposium: Addressing Verification Challenges* (Vienna, Austria, 2006).
[4] J. Oddou, "The Application of 3D Laser Scanning Techniques for the Efficient Safeguarding of Fairly Static Storage Facilities for Natural, Depleted and Reprocessed Uranium," in *Proceedings of the 51st Annual Meeting of the Institute for Nuclear Materials Management* (INMM, 2010).
[5] P. Chare et al., "Safeguards by Design—As Applied to the Sellafield Product and Residue Store (SPRS)," *ESARDA Bulletin* 46 (2011): 72–8.
[6] "Z+F Laser," available at http://www.zf-laser.com.
[7] "FARO," available at http://faro.com.

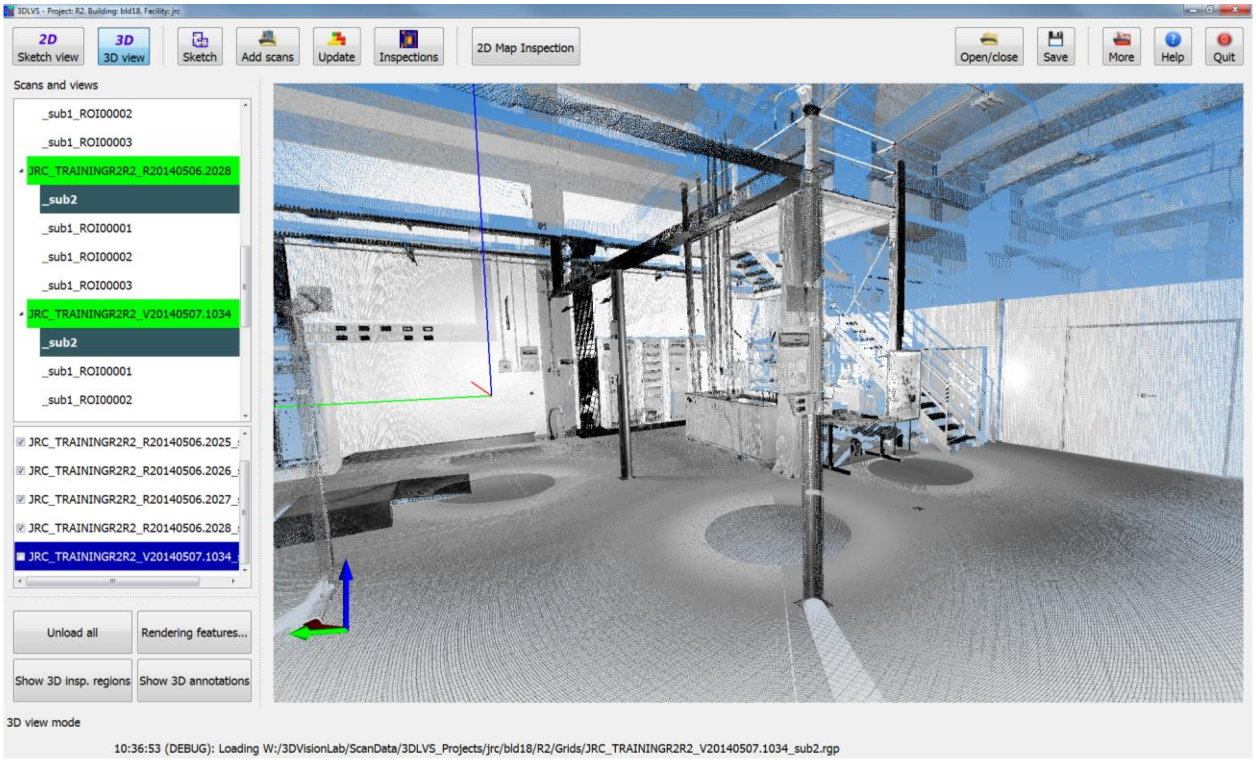

Figure 3: Snapshot of the 3DLVS software used by nuclear safeguards inspectors for design information verification and change monitoring. (Photo Credit: JRC)