IPNDV Working Group 3: Technical Challenges and Solutions
Chain of Custody (2) Technology Data Sheet

September 16, 2016

Chain of Custody (CoC) Technology Name: 3D Identification and Containment
Physical Principle/Methodology of Technology: 3D scanners based on laser triangulation can measure the surface geometry of an object with an accuracy of several micrometers. A laser diode projects a laser point (or line) on the object surface (typically using red laser with a power of several milliwatts); the reflected light is imaged by a digital camera. Using triangulation, the distance between sensor and object can be calculated from the position of the laser point (or line) in the image. The relative pose (position and orientation) between laser and camera determines the stand-off distance, measurement range, and accuracy. Reducing the measuring range will increase the accuracy and vice versa. In order to acquire the complete 3D image, the triangulation sensor needs to scan over the object surface, e.g., using a translation or rotation stage. If the surface geometry of an object has random variations that are larger than the measurement accuracy of the 3D scanner (i.e., tens of microns), it can be used as a signature to identify the object. Examples include the 3D structure of a weld, which is used to close the lid of a material container. As an initial step, all objects need to be scanned to create a database of reference signatures. During verification, the object under investigation is scanned and the acquired signature is checked against the signature database to uniquely identify and/or authenticate the object.
Potential Monitoring Use Cases (pre-dismantlement, dismantlement, post-dismantlement, storage stage): 3D *Identification and Authentication* can be used to ensure the chain of custody during temporary and long-term storage throughout the dismantlement process. It can be applied to all storage containers that have a uniquely identifiable 3D surface structure such as a weld. This use of the technology could be used for building confidence or assuring an item is genuine. Because this technology looks at surface features, scratches, dents, corrosion, paint chipping or flaking on the surface area of interest could cause a misidentification. Additionally, 3D surface scanning might be used to detect tampering with a containment, i.e., it can be applied as a virtual seal for *containment verification*: any variations in the surface geometry that are caused by potential tampering (e.g., opening/closing of a container) can be detected by comparing the verification scan against the reference in the database. This concept presumes that physical damage or deviations occur to the surface of the container during the tamper attempt.
Physical Description of Technology (e.g., approximate size, weight): 3D identification systems for nuclear safeguards are typically custom designs, built for specific verification tasks. The main components (laser diode and imaging sensor) are small and light and the configuration is designed according to the measurement requirements. The complete system might include a translations stage, mounting, and power supply/battery and processing/control computer. The inclusion of these features, which will depend on specific use cases, could make the complete system quite large and heavy, however. See below for examples.
Time Constraints (e.g., measurement times, time to install the equipment):

Installation/Preparation: Typically, the triangulation scanner is a portable device that requires no installation work. As a preparation step, a reference scan needs to be acquired of all objects under verification. The required time depends mainly on the number of objects under verification.

Data Acquisition/Verification: The time for the actual scan is approximately one minute. The total time is specific to the verification task and depends on the accessibility of the object, the complexity of mounting the scanner, and other logistic constraints in the facility.

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

3D identification systems for nuclear safeguards are designed to be used by inspectors on a non-regular basis, i.e., they implement a simple workflow for data acquisition and analysis that does not require expert knowledge or extensive training.

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

The triangulation scanners are typically portable systems that do not require dedicated infrastructure. The analysis software and reference database might run on a stand-alone PC or could be part of a larger IT infrastructure of the inspectorate.

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

The laser triangulation system requires that the laser line that is projected onto the surface can be imaged properly by the digital camera. Therefore, very dark surfaces that do not reflect the laser light and very specular materials where no light is reflected toward the camera can create problems to the system.

The object that is to be identified requires a unique surface geometry that has depth variations of at least several micrometers. It is not necessary to scan the entire object surface; it is sufficient to have a small local area that is uniquely identifiable. There should be no significant variations in the surface geometry over time. The structure can be inherent to the object (e.g., a weld structure for closing a container) or can be applied explicitly for the purpose of identification.

If the identity also needs to be authenticated, it is required that the surface geometry cannot be reproduced, e.g., through 3D printing.

If 3D scanning is used for containment and tamper indication, it is required that the potential tampering causes a modification of the surface geometry that is larger than the scanning accuracy.

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

The triangulation scanner acquires 3D surface information of the object (e.g., container under verification). The 3D information is typically transformed to a more compact descriptor, which does not disclose any sensitive information.

Safety, Security, Deployment Concerns:

The triangulation scanners are designed to be eye-safe. Access to the object and mounting of the scanner might have safety implications.

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

Laser triangulation is a proven technology used widely in industrial inspection in general, and for nuclear safeguards in particular.

Normally, custom solutions are required to solve a specific verification task, which includes the design and development of the laser/camera configuration according to the measurement requirements; the scanning mechanism to cover the entire area of interest; a mounting mechanism and a software solution for data storage and analysis.

Cost Estimate:

The 3D identification systems for safeguards verification are custom developments, which might require one man-year or more for design, development, and deployment. The cost of the components ranges from several hundred to a few thousand Euro.

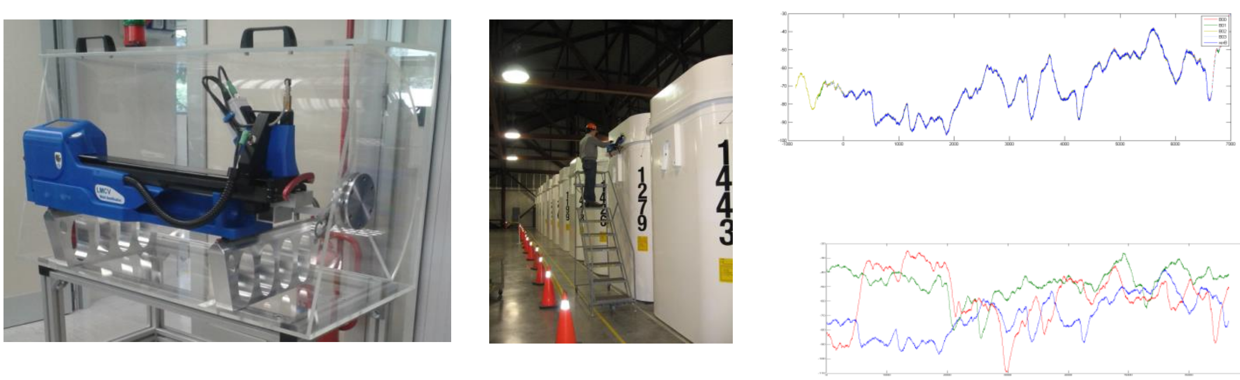
Additional System Functionality (e.g., outside the monitoring use case):

Nuclear safeguards as discussed in other sections.

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

Three examples of 3D laser triangulation systems developed at JRC for nuclear safeguards applications are shown hereafter:

Laser Mapping for Containment Verification (LMCV): LMCV is a 3D laser triangulation scanner that was developed to verify Dry Storage Casks for spent nuclear fuel. It maps the surface geometry of the weld connecting the lid and the main container body to uniquely identify the container and verify the integrity of the weld.[1] LMCV is currently being rolled out at nuclear facilities in Canada and it is also planned to be deployed in Eastern Europe.



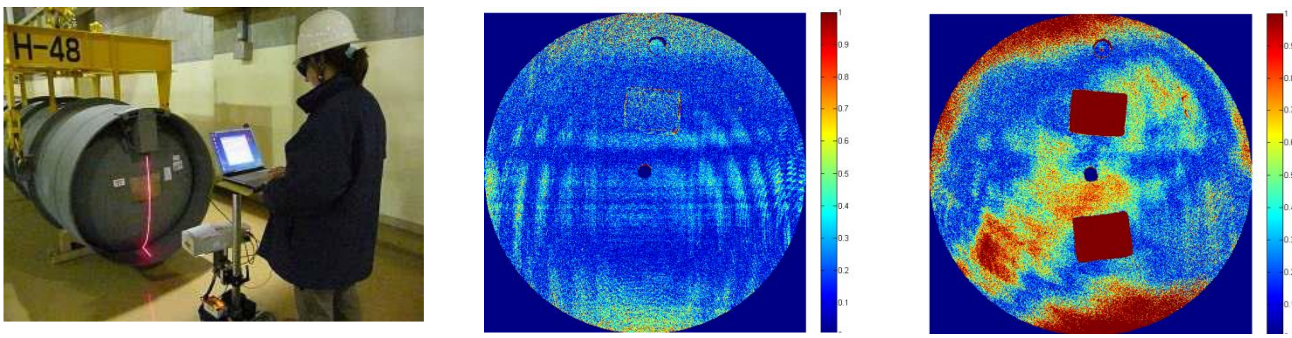
(1) **(2)** **(3)**

Figure 1: (1) LMCV in its docking station, which serves to (1) charge the system and (2) to establish a communication link to the inspectorate's headquarters for remotely accessing the system. (Photo Credit: JRC) (2)LMCV is being mounted on a dry storage cask for acquiring a surface scan of the weld. (Photo Credit: IAEA) (3) Weld signatures that are computed from the surface scans.

[1] P. Taddei et al., "Container Weld Identification Using Portable Laser Scanners," *Journal of Electronic Imaging* 24, no. 2 (2015).

The upper graph contains several signatures of the same weld, showing that the signature is reproducible. The lower graph contains several signatures of different welds showing that the signatures are unique. (Photo Credit: JRC)

Laser Item Identification System (L2IS): The L2IS was developed to automatically identify UF6 cylinders entering the production area at the enrichment facility in Rokkasho, Japan. It scans the front face of the cylinders and uses the manufacturing tolerances of the surface geometry to uniquely identify the cylinders. The system has two distinct units: a portable unit is used to scan all cylinders stored on-site and populate the reference database. An unattended unit installed in the transit corridor automatically detects and scans the cylinders when they are transported into the production area and identifies the matching item in the database.[2]



(1) (2) (3)

Figure 2: Left: Portable unit of the LMCV, which is used to scan all cylinders on site and populate the reference database. (Photo Credit: IAEA) Center: Results of matching a verification scan against the correct reference. Each point indicates the distance between the reference and the verification surface, from dark blue (0 mm), to green (0.5 mm), to dark red (1 mm or above). Right: Results of comparing a verification scan against an incorrect reference. (Photo Credit: JRC)

Stack Scanner @ SPRS: The Stack Scanner was developed for containment verification at the Sellafield Product and Residue Store (SPRS) in the UK. The SPRS has several ventilation stacks penetrating the roof of the building. Each stack contains a horizontal grid blocking access to the building ensuring the containment of the material. The Stack Scanner was developed to detect potential tampering with the grid: during inspections, the inspectors mount the Stack Scanner inside the stack (accessed through a maintenance hatch) and makes a verification scan of the grid. In an off-line analysis, the inspector compares the verification scan to the reference to verify that the grid has not been tampered with.[3]

Examples of Equipment:

See above.

[2] S. Poirier et al., "Laser Based Monitoring of UF6 Cylinders," in *Proceedings of ESARDA 31st Annual Meeting* (Vilnius, Lithuania, May 26–28, 2009).

[3] P. Chare et al., "Safeguards by Design—As Applied to the Sellafield Product and Residue Store (SPRS)," *ESARDA Bulletin* 46 (2011): 72–8.