IPNDV Working Group 3: Technical Challenges and Solutions
Chain of Custody (4)—Technology Data Sheet

September 12, 2017

Chain of Custody (CoC) Technology Name: Accelerometers
Physical Principle/Methodology of Technology: A force always has a magnitude and direction. Accelerometer sensor measures accelerating forces. Dynamic accelerating forces can be converted into information about the movement of the sensor. Notice, e.g., that the accelerometer detects a zero force when the sensor is in a free fall and a non-zero force (caused by the Earth's gravitational force) when staying still, imagine the length change of a spring-weight system attached to a roof and in a free fall. Sensors that detect one-, two-, and three-dimensional movements are commercially available. Various working principles are used in accelerometers. Common option is to use piezoelectric effect. Opposite surfaces of the piezoelectric crystal become charged if pressed toward each other. Net charge is zero inside the crystal. Therefore, the resulting electrical charge is independent of the crystal thickness. The created charge is directly proportional to the amount of force pressing the surfaces toward each other. Pressing from other directions does not charge the surfaces. Piezoresistive effect is also used in sensors. Its principal idea is that the stress influences the resistance of the sensor material. In capacitive Micro Electro Mechanical Systems (MEMS) sensors, the accelerating force alters the distance between two sensor surfaces. This changes the capacitance of the measuring system. Capacitive MEMS sensors would probably suit better to the present application than Piezo sensors. Capacitive MEMS sensors are, for example, used in mobile phones. Piezo sensors are typically used to measure higher g-forces and frequencies. There are also other techniques available and used in accelerometers. An accelerometer's noise level defines its sensitivity. A system's digital resolution needs to be such that the noise can be resolved. This is usually not a problem since, for example, 14-bit analog to digital converter could be used (2^{14} = 16,384 channels). Averaging over time improves the sensitivity with the cost of time resolution. Inclinometers using Earth's gravitational force are used here as an example to demonstrate the sensitivity and time resolution of MEMS sensors. State-of-the-art commercially available inclinometers have a noise level around 0.001° with 10 Hz bandwidth. So, in practice very minor changes in orientation or in other movements could be detected with a MEMS sensor. It is actually quite doubtful that one could mechanically create movements that would not be detected with a properly designed sensor system.
Potential Monitoring Use Cases (pre-dismantlement, dismantlement, post-dismantlement, storage stage): Accelerometers could be used to monitor the storage and movement of containers containing Nuclear Explosive Devices (NED, if sensor could be directly connected to the NED container) and their components without exposing sensitive information related to the weapons, facility, or its personnel, i.e., they could be used in situations where camera surveillance is not possible but continuous unattended monitoring is required. If needed, accelerometers could also be used for monitoring and motion detection of other objects. For broader monitoring purposes accelerometers could be attached to mechanical structures, doors, cranes, tools, detectors, etc.

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

Sensors are small and light weight. The price of one sensor is on the order of $1 USD if a larger amount is bought. They could be accompanied, for example, with a battery and a local data logger. Dimensions of the entire packed system could be approximately 4x3x8 cm^3. The system could be placed inside a sealed box that is connected to the object whose movements are monitored. After activation deployed systems would be left unattended to do the monitoring until the next inspector visit. During the surveillance and maintenance visits, inspectors could change or load the batteries and download the collected data for analysis, e.g., using a USB interface.

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

Set up time is short if everything is prepared in advance. Accelerometers can stay up and running as long as needed if external electricity is available. If only operated with a battery power, the expected operating time is from months to years depending on the batteries. In order to consume as little electricity as possible, the monitoring system should be configured in such a way that only the clock and motion sensors are awake when nothing is happening. The system would be in a so-called motion detection mode. When movement is detected, the sensor awakes the rest of the system to record and analyze the event. The system could be built so that when a signal rises above a decided threshold level, the values measured shortly before the incident also are stored. Data storage capacity should not be a limiting factor.

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

Technology is easy to use and the analysis method is also reasonably straightforward. Automatic analysis routines could be developed.

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

Storage containers or equipment whose movements or operation need to be monitored should preferably have a separate sealed box where the sensor system could be placed.

Technology Limitations (e.g., operational temperature range, differences in materials):

Technology is operable indoors without problems. MEMS sensors that can operate between the -40°C to 125°C temperature range are commercially available. Battery life-time sets some limits to the usability.

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

The technology of the sensor tells if the container or other object where the sensor is connected has moved or has mechanically been manipulated during the monitoring period. If the container or other object has moved, the system can tell when it happened and where it went.

Safety, Security, Deployment Concerns:

The selection of a proper battery is perhaps a safety issue.

Technology Development Stage (Technology Readiness Level, TRL):

TRL 7: Accelerometers are in operational use in other applications but have never been applied for nuclear disarmament verification.

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

Other sensors such as light, temperature, humidity, or pressure could be connected to the same data logger. Additional sensors could shed more light to the analysis of accelerometer data. Additional sensors would increase the consumption of electricity.

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

Accelerometers are used in engineering, biology, industry, building and structural monitoring, medicine, navigation, transport, volcanology, consumer electronics (motion input, orientation sensing, image stabilization, device integrity), and gravimetry.

Examples of Equipment:

https://www.bosch-sensortec.com/bst/products/products_overview

http://www.murata.com/products/sensor/accel

http://www.st.com/content/st_com/en/products/mems-and-sensors.html

http://www.msr.ch/en/product/msr145.php

http://axivity.com/product/ax3