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Request for Information on the National Digital Twins R&D Strategic Plan

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<u>**RFI Response: Digital Twins R&D Plan**</u>

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In many applications relevant to the Department of Energy, National Nuclear Security Agency, Department of Homeland Security, and Department of Defense, such as nuclear detection, nuclear safeguards, nuclear safety, radiological emergency response, and environmental contamination mapping, it is highly important to understand the distribution of radioactive material and the transport of emitted radiation in an area of interest. In these scenarios, contextual sensors such as lidar can create a three dimensional digital model of the mapped environment, while radiation detectors can make measurements of radiation fields within the environment. Increasingly, multi-sensor systems that combine radiation detectors with contextual sensors are deployed on robotic platforms.

It is possible to enhance the scene model with information extracted from the contextual data by, for example, analyzing data from cameras with semantic segmentation neural networks to extract material composition. Ultimately, this process results in the real-time generation of a detailed digital twin of the measurement environment.

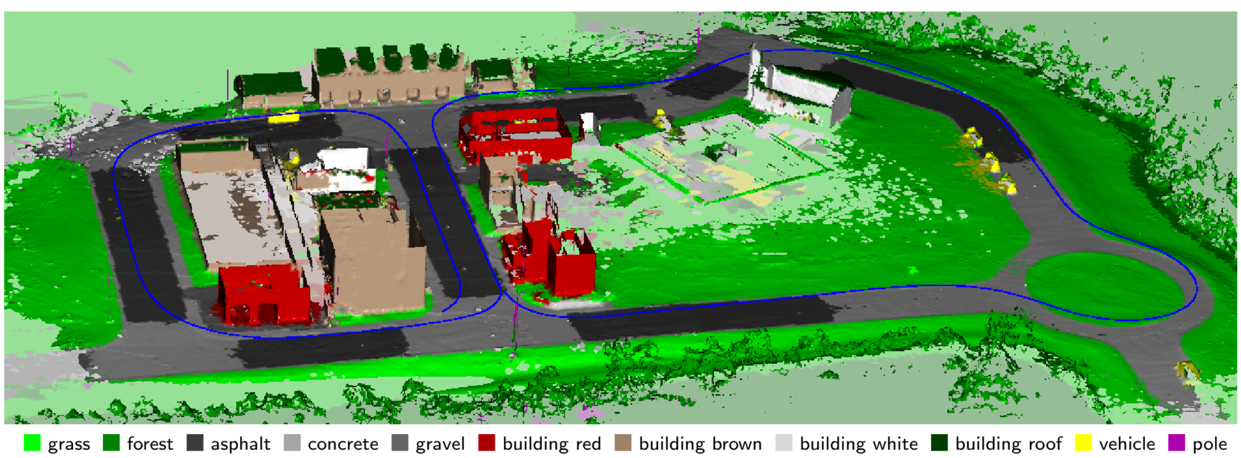

Figure 1: Digital twin of an urban scene. The 3D model is constructed with lidar data collected on a vehicle-based system. The path of the vehicle is indicated in blue. The segmentation of the facility is done by neural networks, processing 360 degree images collected with cameras installed on the vehicle.

This digital twin can be used as a basis for modeling the real-world measurement and enabling real-time analysis of the experimental data. For example, knowledge of the physical environment is essential for the inversion of measured radiation data to time and location dependent dose rates or activity concentrations, and to inform the navigation of the robotic platforms that may be tasked with performing actions in radioactive environments. The combination of the digital scene model and radiation map(s) can inform further responses by providing estimates of optimal sensor placement, required dwell times, or remedial actions. In order to do this, continuous, low-latency feedback between the digital twin and the physical system is required; new sensor data flows to the model and the model informs further actions taken in the real world, leading to new sensor data.

This approach is relevant to operators of nuclear facilities, in nuclear safeguards, emergency response, and environmental cleanup and sampling efforts. It can inform radioactive activation and contamination at classical and small modular fission reactors, fusion facilities, scientific research facilities (accelerator beam lines, etc), and medical institutions. Similarly, the characterization and clean up efforts related to nuclear dispersals (accidental or otherwise) and from legacy nuclear activities can inform navigation of operators and autonomous systems, for example to allow responders and troops to navigate a contaminated area safely. Likewise, transport and disposition of radioactive materials in clean-up scenarios can be studied and optimized to minimize exposure risks to the public and personnel. In emergency response scenarios a digital model could be used to understand the probing of an item of concern, informing the placements of detector systems and advising actions to render the item safe. The use of off-the-shelf sensors, the creation of a digital version of a specific region of the real world, modeling physics, that then influences further data collection, is an important application of a digital twin to real world problems.

Ongoing and future research and development efforts for digital twins in radiological mapping should focus on using the digital twin to drive decision making for autonomous systems as well as for humans-in-the-loop analyses of potentially high-consequence actions in, for example, radiological emergency response. When deployed on a robotic platform such as a ground vehicle, quadruped, or unmanned aerial system, autonomous decision making algorithms can remove human operators from laborious and/or dangerous activities related to performing radiological measurements and gaining situational awareness. Existing robotic workflows are largely automated but not fully autonomous (e.g., following a predefined survey pattern, perhaps with some level of obstacle avoidance), and basing autonomy algorithms on the radiation map (rather than just the digital scene model) remains an ongoing research topic deserving of much more effort.

When humans are engaged in the decision making process, a digital twin can help inform ‘what-if’ scenarios imagined by the decision-maker, and that can be investigated digitally prior to allocating resources and/or providing directives. An example of such a use could be a nuclear emergency response scenario. Such a scenario can involve first responders encountering an item containing radioactive material that could potentially be associated with a nuclear weapon or radiological dispersal device. In these cases offsite experts are tasked with providing guidance to onsite personnel to make measurements and potentially perform high-risk actions with the goal of reducing the potential health and economic impacts of the radioactive item. During the response, the ability to rapidly generate a digital twin to support decision making and physics-based what-if analyses would be a great asset to the country.

Fundamental improvements to the quality of radiological digital twins would motivate their use more widely. In particular, while the current-generation digital scene models help to constrain the domain over which radionuclide concentrations can be reconstructed, it is computationally challenging to use these scene models to correct for attenuation from objects in the environment. This lack of attenuation correction is known to bias reconstruction results, potentially limiting the real-world fieldability of radiation mapping technology in certain complex environments. Computationally-efficient attenuation modeling should therefore be a high research priority for radiological digital twins.

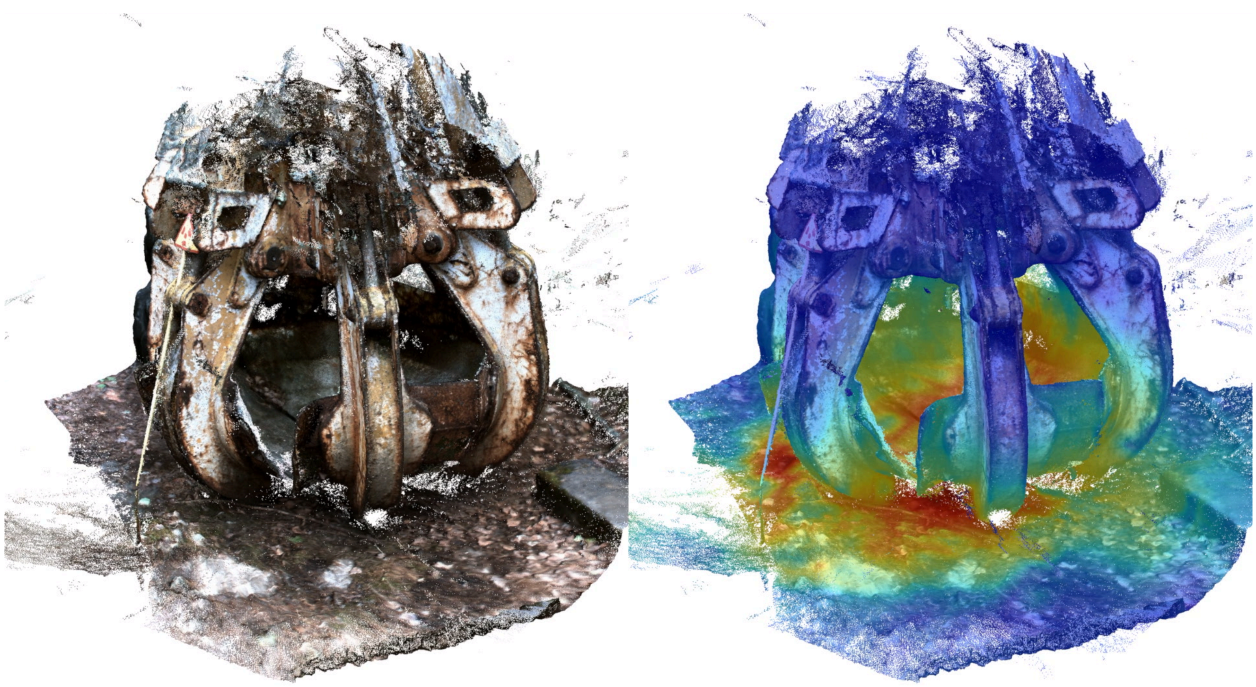

Figure 2: The left panel shows a 3D reconstruction of a crane claw that was used to move nuclear fuel and debris in the Chernobyl exclusion zone. It is created by processing a video with photogrammetry. The right panel shows the same view, overlaid by a map of contamination (red indicates high contamination, blue indicates low

contamination). It is created by modeling the transport of radiation through the "digital twin".

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