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ADVANCING SAFETY IN NUCLEAR APPLICATIONS WITH REDUCED ORDER MODELING AND DIGITAL TWIN

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ABSTRACT

Ionizing radiation refers to particles or photons that carry enough energy to remove electrons from atoms or molecules. Through ionizing interactions, radiation can have severe implications for human health and the environment, making it essential to develop effective strategies to manage the risks it poses. To display the potential benefits from the application of digital twin technologies to concerns regarding radioactive material in laboratory, university, and national defense settings, this paper presents the development of a digital twin framework, and potential use cases for the framework. The platform was demonstrated in two scenario studies. The first scenario involves a faux radiation-detecting glovebox used for lab safety education, while the second scenario addresses training for first responders in a nuclear defense and safety situation.

1 INTRODUCTION/MOTIVATION

With the introduction of the new generation of nuclear reactor designs and the general renewed interest in nuclear power in states with and without existing nuclear energy, there presents the need for more modern approaches to promote and verify the responsible usage of nuclear material. This can be reflected in the '3S' principles-safety, security, safeguards, which are concepts in the nuclear field that are used to describe practices, systems, or designs that promote responsible use of nuclear and radioactive material. Being able to properly account for, and track and visualize sources or radiation can better enable workers to avoid radiation hot-spots, as well as prevent the removal or diversion of radioactive material in an unauthorized manner. As a proof-of-concept, a framework was produced for a digital twin to explore applications of the emerging technology to nuclear-related work. The term digital twin refers to a digital representation of an object or system that exists in the physical world, where the digital and physical assets are linked through the active transfer of data between each other. The constant connection between the assets allows for the advance visualization of data from the physical asset, as well as predictive analysis for determining future states of the asset. Digital twin technology can aid in tracking and visualizing where this material is, leading to improved accounting. This technology opens up new pathways that can reduce health risks to workers, allow easier material accounting, and aid in the detection of unauthorized removal of materials.

2 METHODOLOGY / RESULTS

The digital twin framework that was produced through the integration of several key components, comprising the asset or location 3D model, the data exchange system and protocol, and the predictive model for the scenario. Unreal Engine comprised the basis for the digital twin system and provided the platform for which all parts components of the twin were integrated. The 3D model representing the asset geometry provided the most basic visual component of the system and was designed to be as close to the real physical asset as possible. Communication between the digital and physical model utilizes the message queueing telemetry transport, or MQTT, messaging protocol. MQTT was chosen due to its wide adoption in the Internet of Things (IoT) realm, as well as being lightweight and easy to implement within the game engine. The final component, the predictive model, was implemented through the development of a reduced-order model and localization scheme. Reduced-order modeling was used to generate an expected relationship between the radiation sources and the detectors in the physical asset. Using the expected relationship, the estimated detector response data was then produced as a baseline for which the real response data of the physical asset would be compared. Radioactive sources present in the real world could then be located and displayed in the digital representation based on the observed detector reading. The localization of the sources was achieved through the minimization of the error between the expected response generated and the real response.

Visualization aspects were added to the digital twin to better convey important information within the digital environment. These visualization aspects include text displays, 3D representations of objects introduced into the system, and color elements, such as heat maps, depending on the scenario. Inclusion of visual aids promotes the flow of information from the digital twin to the physical asset through in the form of informed operator decisions.

3 CONCLUSIONS

This study examined the applicability of digital twin technologies to settings where radioactive or nuclear material may be encountered. The examination was conducted through the creation of a digital twin framework, which integrates cutting-edge visualization technologies with reduced-order modeling methods to address these concerns. Two scenarios were created to demonstrate the versatility of the framework, the first scenario involving a simulated radiation detection glovebox designed for laboratory safety education, while the second scenario related training first responders to handle nuclear defense and safety situations. The application discussed to the scenarios shows clear potential for a versatile digital twin, usable in a variety of nuclear radiation education and safety scenarios.

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