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

Knights Digital Twin Initiative, University of Central Florida,

Institute for Simulation and Training / School of Modeling Simulation and Training

The UCF's Knights Digital Twin Initiative Research and Development

Submitted by:

Knights Digital Twin Initiative, University of Central Florida,

Institute for Simulation and Training / School of Modeling Simulation and Training

Contributors: Soheil Sabri[1], Grace Bochenek[2], Dirk Reiners, Carolina Cruiz-Niera, Ghaith Rabadi, Scott Dillon, David Metcalf, Sean Mondesire, Mohamed Abdel-Aty, Amir Mahdiyar, Mahdi Aghaabasi, Bulent Soykan, Michael Eakins, Zijin Wang

Executive Summary:

Through its Knights Digital Twin Initiative, the University of Central Florida (UCF) responds to the U.S. government's Request for Information on Digital Twins (DT), addressing critical aspects of Artificial Intelligence (AI) integration, verification and validation, and workforce development. Drawing on expertise from specialized labs, UCF highlights key challenges and future directions in digital twin technology. In AI integration, the focus is on mitigating hallucinations in generative models for critical applications. For Verification, Validation, and Uncertainty Quantification (VVUQ), UCF emphasizes standardized frameworks and improved real-time modeling and simulation modeling techniques. when it comes to workforce development, it emerges as a crucial area, with recommendations for interdisciplinary training and standardized accreditation. An additional area that is not adequately represented in current DT research is the question for the most effective way to present and interact with DT systems. Key priorities for future focus include enhancing AI accuracy in digital twins, creating standardized VVUQ frameworks, establishing comprehensive training programs, and addressing the cybersecurity workforce shortage. UCF proposes strategies such as developing national computational resources, implementing advanced modeling techniques, and fostering academia-industry partnerships. By addressing these challenges and implementing the proposed strategies, the U.S. can strengthen its position in digital twin technology, driving innovation and maintaining global competitiveness across various sectors. This response provides a roadmap for advancing digital twin capabilities in the abovementioned topics,

[1] Corresponding author: [redacted]

[2] Director, IST/SMST and lead, Knights Digital Twin Initiative: [redacted]

emphasizing the importance of collaboration between academia, industry, and government in this critical technological domain.

Introduction:

This document aims to provide comments and insights in response to the Request for Information (RFI) issued by the U.S. government, Networking and Information Technology Research and Development (NITRD) National Coordination Office (NCO), and National Science Foundation (NSF). The University of Central Florida (UCF) has actively engaged in digital transformation through its pioneering Knights Digital Twin (KDT) Initiative[3]. The KDT Initiative, led by the School of Modeling Simulation and Training (SMST) embodies UCF's commitment to innovative digital transformation, and several specialized labs have been instrumental in this effort. Moreover, it positions UCF at the forefront of advancing the U.S.'s global competitive advantage by fostering collaboration across academia, industry, military, and government. The ultimate goal of this initiative is to develop an integrated ecosystem comprising digital/physical twins, data, models, simulations, and comprehensive lifecycle analyses within a multi-domain environment.

In this document, we address three critical aspects outlined in the RFI: "*AI and Digital Twins," "Verification, Validation, and Uncertainty Quantification for Digital Twins: Possible focus areas," and "Workforce Development".* It is worth mentioning that all mentioned gaps provided in the following section are purely based on the real-life experiences and insights of KDT-UCF experts in the adoption and implementation of digital twins in various aspects and based on extensive research experiences.

Through this response, UCF aims to provide valuable insights and recommendations that will support the U.S. government's efforts in harnessing the potential of digital twin technology. By addressing these key areas, we strive to contribute to the development of robust, innovative, and effective digital twin solutions that can drive progress across various sectors. We look forward to continued collaboration and the opportunity to contribute to the advancement of digital twin technology, reinforcing the U.S.'s position as a global leader in digital innovation.

[3] https://www.ist.ucf.edu/labs/knights-digital-twin-initiative/

AI and Digital Twins:

State-of-the-Art

The state-of-the-art artificial intelligence (AI) with digital twins is the ability to combine real-time data collection, data modeling for analytics, and explainable AI to assist in human decision-making. These intelligent digital twins are leveraging advancements in GPU hardware, large language models (LLMs) including Generative AI, and optimized machine learning algorithms to accelerate automated identification of trends and insights within vast quantities of data and explain to the user why the AI is making certain recommendations in easy to understand written and spoken word. There are several examples to illustrate the impact of these advancements. First, semiconductor manufacturing technicians can identify when expensive equipment will fail and when preventative maintenance should occur and receive an automated explanation of why something is occurring. Secondly, intelligent digital twins can dynamically represent individual military personnel's comprehension level of new training and present custom remediation to the trainee to solidify their concept understanding. A third example is that through AI and digital twins, ground vehicles and aircraft can be modeled to provide insight to manufacturers into how drivers and pilots are truly using the hardware for next-generation system design and rolling software updates, similar to Tesla’s over-the-air software updates that improve the efficiency and safety of their vehicles.

Furthermore, often times our government and military sponsors / partners have limited access, restrictions, or limited bandwidth to research cutting-edge technologies such as AI. KDT-UCF employs an evergreen method of meta-analysis with a focus on post-quantum technologies and it has been a leader in integrating protocols and standards based on blockchain, NIST, and MIL-STD guidelines and regulations. Industry and government organizations' guidance on digital engineering and performance continues to steer the multimodal integration of explainable and assured AI for multiple data inputs and outputs to Digital Twins. This integration extends beyond web and mobile interfaces to include AR/VR/XR and, where appropriate, holographic 3D displays and other novel modes of Digital Twin integration. For example, KDT-UCF receives a Department of Energy (DOE) Minority Serving Institution Partnership Program (MSIPP) grant. This grant will help train a workforce prepared to address DOE missions involving nuclear security through the use of AI, Digital Twins, AR/VR, and other novel technologies such as

holographic tables and haptic feedback gloves. A holographic table (10” in depth with no glasses) will soon be housed at the Institute for Simulation & Training (IST). Interested partners in Digital Twin research, tabletop exercises, and more will use it. I will utilize this table and an AI application layer to control assets in scenarios / Digital Twin simulations.
In addition, we often helps our sponsors/partners accomplish AI-based DT technologies as an honest broker of technology while understanding the requirements of government and military contexts and needs when vetting solutions such as LLMs, visualization hardware, etc.

Unsolved Gaps / Limitations:

The most significant limitation of generative AI in digital twin deployment is their susceptibility to presenting wrong information as fact. These *hallucinations* are acceptable in general usage, such as with OpenAI’s ChatGPT, but not in serious scenarios, such as in healthcare, personnel training, and business operations. Methods are needed to enhance the accuracy of generated results and build trusted AI models.

We are actively exploring methods to mitigate hallucinations and elevate the accuracy of LLMs in the use of automated reporting for intelligent digital twins. We are also developing methods to assess the quality of LLMs, designing new methods to improve model memory through fine-tuning techniques, and generating methods that combine the strengths of multiple LLM models interacting with each other to find consensus before generating final responses.

Recommended Government Support for Solutions:

- Research funding opportunities should be created to develop standards for digital twin integration with generative AI models.
- National computational resources should be provided to researchers to develop, test, and enhance their digital twin projects. Particularly, generative AI is computationally expensive. National digital twin computational resources will lower the barrier to scientific entry and support innovation typically stifled by limited computational support.
- Central data repositories should be created so researchers can focus on developing digital twins and spend less time on data acquisition. Data drives digital twins and artificial intelligence. A nationally supported repository will seed model creation and innovation.

Develop Rigorous Methods for Verification, Validation, and Uncertainty Quantification for Digital Twins:

State-of-the-Art

Verification, Validation, and Uncertainty Quantification (VVUQ) is a critical process in ensuring the accuracy, reliability, and applicability of complex models and simulations, particularly in the context of digital twins. This process involves systematically assessing the correctness of model implementation, evaluating how well the model represents real-world phenomena, and quantifying uncertainties in model predictions.

As a part of our efforts, we focus on developing digital twin solutions for urban mobility monitoring, leveraging existing infrastructure, advanced computational models, and state-of-the-art system integration to enhance traffic safety, mobility, and sustainability. These works have led to the adoption of these systems by Traffic Management Centers for visualizing mobility patterns and implementing proactive traffic management strategies.

We conducted research on various issues at the urban scale, such as human mobility, climate change adaptation, and critical infrastructure (e.g., smart airports). We are also involved in developing advanced methods for multi-dimensional data collection (2D, 3D, real-time) and harmonization, geospatial systems interoperability, Geospatial AI (GeoAI), and real-time urban modeling and simulation. Enabling intelligent decision-making in digital twins, we develop hybrid models that quantify uncertainties using fuzzy-based, ensembled, and multi-criteria decision-making methods.

Meanwhile, the we are exploring the integration of advanced VVUQ techniques, such as Bayesian inference and Markov Chain Monte Carlo (MCMC) simulations, into digital twin ecosystems across various domains, with a particular emphasis on high-stakes sectors like healthcare, where they are validating digital twin models of human organs to predict surgical outcomes with high accuracy.

Unsolved Gaps / Limitations:

A recent work of our team has revealed significant gaps and challenges in VVUQ for digital twins, particularly in urban contexts. We identify the need for comprehensive integration of sub-domains in urban mobility digital twins, difficulties in transitioning research to practice, and the

lack of systematic assessment frameworks. We also report challenges in accurately modeling diverse urban environments, managing heterogeneous data, and integrating subsystems with varying uncertainty levels. They also identified issues in validating models against limited real-world data, particularly for rare events (e.g., urban storm waters), and quantifying uncertainty in complex urban settings with human-infrastructure-technology interactions. In addition, we highlight the challenges in developing robust methodologies to handle inherent uncertainty, especially with limited or noisy data and integrating VVUQ into digital twin ecosystems. We also report issues of interoperability, standardization, and the complexity of multi-scale and multi-physics modeling.

Recommendations

- Develop standardized VVUQ frameworks, protocols, and evaluation methods specific to urban digital twins, including improved infrastructure for real-time data collection, management, and integration of heterogeneous sources.
- Implement advanced modeling techniques, including machine learning, multi-scale, and multi-physics approaches, to enhance computational efficiency, scalability, and adaptability to changing urban dynamics.
- Improve uncertainty quantification methodologies, particularly for complex systems and human behavior models, and develop innovative visualization techniques to communicate uncertainty to decision-makers effectively.
- Establish partnerships with city authorities and urban planners for real-world validation, creating benchmark datasets and rigorous cross-validation protocols using diverse urban scenarios.
- Invest in high-performance computing infrastructure and interdisciplinary research teams to address the multifaceted nature of urban systems and facilitate large-scale simulations.
- Bridge the gap between research and practice by developing methods for continuous model updating, learning from real-time urban data, and transitioning mobility research into practical, applicable systems.

Cultivate Workforce and Training to Advance Digital Twin Research and Development: Possible focus areas:

Current State of the Art

Workforce development in the age of Digital Twins has not only integrated with advanced technology and processes but also aligned with a culture of an intergenerational workforce. Next-century skills and a focus on critical thinking, caring, and quality are important life skills focused on society's needs amid a fast-approaching transhumanist capability set. Specifically, Modeling and simulation workforce development has become pivotal in nurturing the skills necessary to advance digital twin technologies. In recent years, there has been a remarkable upsurge in the demand and interest surrounding applications that necessitate the development of digital twins.

The SMST focused on training and education to address the gap in digital twin expertise and future workforce demand. Our team received a three-year grant from the Department of Education for graduate certification on the digital twin to equip the next generation of professionals from diverse backgrounds and industries with the knowledge and skills necessary to harness the potential of the Digital Twin technology.

Through the development and delivery of this certificate, we empower graduates, including minoritized students, with the expertise they need to design, implement, manage, and innovate using Digital Twin solutions. The program is designed to accomplish the following objectives: (1) Develop a graduate certificate program in Digital Twin (CDT); (2) Develop and implement a multi-mode version of CDT to allow students to complete the program online, in person or hybrid mode; (3) Immerse students in industry and research motivated by real-life applications for effective workforce development in modeling and simulation; and (4) Serve Hispanic and other underrepresented student populations with intention.

Our target population comprises professionals from diverse industries such as manufacturing, education, energy, healthcare, transportation, defense, and smart cities, among others. This includes simulation analysts, engineers, data scientists, social scientists, urban planners, project managers, and executives who seek enhanced DT skills and knowledge.

In addition, we received a training grant from IEEE Systems, Man, and Cybernetics Society to focus on the fundamental skills and knowledge necessary to prepare, integrate, and utilize Digital Twin technologies to create real-time visualizations and presentations. The program will upskill the current professionals in various domains to prepare multi-dimensional data and integrate it into a DT for the application of models and simulations in potential use cases (e.g., fall detection, indoor navigation/wayfinding, routing, and identifying traversable routes) within the DT environment. The program will also cover GeoAI, Geospatial ML (GeoML), and Geospatial IoT (GeoIoT) as available technologies, standards, and possibilities of AI, ML, and IoT in geospatial contexts. Thus, this course will provide a foundational understanding of the range of possibilities of Digital Twins to support data-driven decision-making.

Unsolved Gaps / Limitations:

With our nation facing a shortage of cybersecurity professionals, we highlight the need for workforce development pipeline that increases recruitment and skills training in AI, Blockchain, and Cybersecurity (post-quantum), and quantum computing in DT training programs. There is a desire from groups such as the Department of Energy to train this workforce early and from within.

Another notable gap is the insufficient integration of interdisciplinary training in graduate programs. Traditional curricula often do not encompass the cross-disciplinary skills necessary for Digital Twin technology, such as combining AI, VVUQ, and domain-specific modeling and simulation. Furthermore, there is a lack of standardized accreditation and certification programs for professionals specializing in Digital Twins. This impedes the recognition of skill sets and expertise, limiting career advancement opportunities. Current pedagogical approaches may fall short in providing hands-on experiences and practical applications, which are crucial for mastering the complexities of digital twin ecosystems.

We are receiving a Department of Energy Minority Serving Institution Partnership Program (MSIPP) grant. This grant will help train a workforce prepared to address DOE missions involving nuclear security and cybersecurity through the use of AI, Digital Twins, AR/VR, and other novel technologies such as holographic tables and haptic feedback gloves. Through this MSIPP grant, we will hire students to work on real-world projects for DOE, participate in DOE internships, and have a path to DOE careers.

Recommendations

- Interdisciplinary Curriculum Development: Encourage and support the creation of interdisciplinary curricula that integrate AI, VVUQ, and domain-specific modeling and simulation within graduate programs for digital twins.
- Standardized Certification Programs: Develop and implement standardized certification and accreditation bodies for digital twin professionals to ensure recognized expertise and skill validation.
- Collaboration between Academia, Industry, and government: Foster partnerships to align graduate programs with current and future industry needs, hands-on training, and enhancing employability and innovation.

New Topic: User Interfaces and Visualization for Digital Twins

This topic was not listed in the RFI and it was also not included in the National Academies report, which we think is a significant omission.

Current State of the Art

Currently the research in DTs is understandably focused on the simulation and sensor integration aspects of DTs. If they have any user interface at all and are not just simulations, the user interfaces for these DTs are general fairly simple and come in the form of, mostly web-based, dashboards to observe and control the DT operation. We expect this to be insufficient in the future for more complex and interconnected DTs, especially if more complex aspects like uncertainty and what-if configurations and simulations need to be included and communicated.

Unsolved Gaps / Limitations:

Effective means of visualizing and interacting with large DTs of complex systems is not a very well understood field. Current dashboards are limiting in their expressiveness and information density, and we expect that new, different methods will be needed to fully utilize all the information a DT can provide.

Recommendations

We think it would be beneficial for the field as a whole to start thinking about scalability and visualization issues that will arise with the more wide-spread use of DTs and the expected

increase in complexity of the developed DTs. It is early enough that the groundwork can be done in time for large-scale deployment of DTs. More work in better understanding of the UI/visualization requirements of DTs will enable better matching of display and interaction methods that allow optimal utilization of the DT results. Exploration of immersive visualization as well as in-field augmented and other more direct and immersive interactions will enable us as a nation to reap the benefits of our Digital Twin leadership.

Conclusion

In response to the U.S. government's Request for Information on Digital Twins, the Knights Digital Twins Initiative at the University of Central Florida has identified significant gaps and future directions in three key areas: AI integration, verification and validation, and workforce development. The primary challenge in AI and digital twins is mitigating hallucinations in generative AI models, especially for critical applications. The gaps for verification, validation, and uncertainty quantification (VVUQ) include standardized frameworks, improved uncertainty quantification methodologies, and better integration of VVUQ into complex digital twin ecosystems. Workforce development faces challenges like insufficient interdisciplinary training and a lack of standardized accreditation for digital twin professionals.

To address these issues, UCF recommends focusing on four key areas in the future: developing robust methods to enhance AI accuracy and trustworthiness in digital twins; creating standardized VVUQ frameworks specific to real-time modeling and simulation; establishing comprehensive interdisciplinary training programs for digital twin professionals; and addressing the cybersecurity workforce shortage in the context of digital twin technologies. In addition, we highlighted the significant value of immersive visualization and interaction to optimize the utilization of DTs. These priorities, along with implementing advanced modeling techniques, creating national computational resources and data repositories, and fostering industry-academia-government partnerships, aim to advance U.S. capabilities in digital twin technology across various sectors. By addressing these gaps and implementing the proposed strategies, the U.S. can strengthen its position in digital twin technology and drive innovation in this critical field.