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"Unreal" factories: Next generation of digital twins of machines and factories in the Industrial Metaverse

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ABSTRACT

In its current technology form, digital twins are 3D representations that still lack the realism necessary to enable digital twins to progress towards virtual collaboration and high-fidelity simulation. In this short paper, ten technologies necessary to build the next generation of digital twins of factories are elucidated with a focus on real-time rendering while capturing dynamic states within machines, two-way real-time data transfer between assets and synthetic generation of factory states. Potential applications are also outlined to enable the community to further imagine technology needs and research questions that arise as the next generation of Digital twins are developed.

1. Introduction

We put forward the question on whether we can build entire factories in cyberspace, with the level of high-resolution detail necessary to make it feel as real as the physical factories in the real world. For a decade or so, the community has been developing digital twins of products, machines, and factories [1–6]. We have only scratched the surface of what is possible in terms of the Digital Twin technology in the context of manufacturing. In its current technology form, these digital twins are mere 3D representations that still lack the realism and physical reality necessary to make digital twins of factories in the virtual world to appear real. For example, the digital twins of machines in factories are low-resolution, low-poly detail of machines which indicate basic placement and movement of assets within factories. It has not been used to demonstrate the state of the product in near real-time within the machine or demonstrate the as-is state of factory operations.

The emerging developments in the Industrial Metaverse and associated Virtual Reality fields have the potential to transform engineering education and worldwide collaboration in manufacturing [7]. This Blue-Sky concept paper proposes the next generation of technology development that can help realize virtual "Unreal" factories, with the goal of improving communication, accessibility, and productivity across the value chain to lay the foundation of technologies that move the needle beyond the goals of Industry 4.0. The technology necessary to scale to real-time live immersion and collaboration in virtual factories by users thousands of miles away is just not available today.

Current digital twins of manufacturing machines, say, a Metal Additive Manufacturing or a conventional CNC Milling machine, cannot be used to simulate what happens in the physical world during the manufacturing process. Many digital twins of such machines lack the real-time capability to model in-process state of the workpiece, the surface finish of the fabricated parts or the wear patterns of cutting tools as they are used in the process within the 3D sim world. These 3D simulations even lack the sound that real physical machines generate during the fabrication process. The simulations also lack the texture associated with materials and machines that we as humans experience in the real world. Most digital twins of factories are meant to simulate kinematics of objects within the factory. None of the digital factories represent the as-is state of physical factories as they evolve over time. There is very limited transfer of data from the physical factories and their associated machines to communicate in real-time with their digital counterparts in the cloud. The lack of synchronization between real physical assets and its virtual counterparts limits the applicability of the Digital Twin. We also simply lack meaningful use of computing power and innovations in scene descriptions and digitizable infrastructure necessary to represent factories in cyberspace to make it feel as real as possible.

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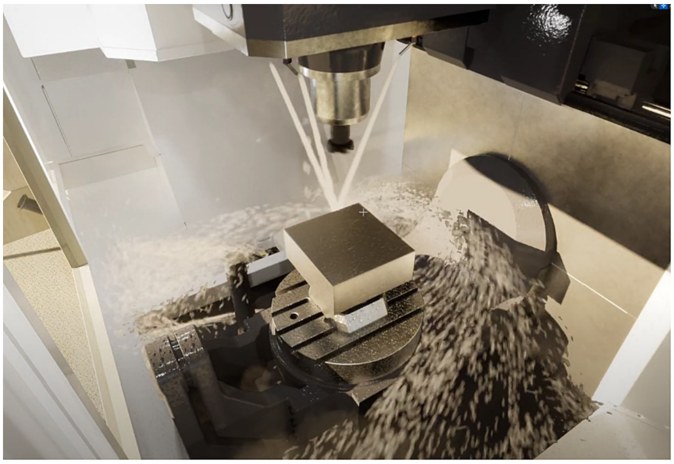

Fig. 1. A real-time simulation and visualization of a CNC cutting operation using the Unreal Game Engine 5.0 platform running on a ubiquitous nVidia RTX 3080 GPU. Coolant properties from viscosity, pressure, temperature and workpiece material properties is factored in during the simulated operation. A video playback is . available at [8]

2. Ten technologies necessary for 'Unreal' factories

The following section describes ten technologies that would be necessary for an 'unreal' like immersive experience within virtual factories that emulate real factories. These solutions would be necessary to realize the next generation of digital twins that represent a network of virtual factories and the infrastructure that is contained within them.

(1) ***Digitizable materials and digitizable factory infrastructure:*** Low-cost, energy-harvesting methods to digitize materials, floors of factories, and digitizable machine infrastructure to compute and send data to its virtual counterparts.

(2) ***Real-time Streaming & Computing of factory data to its digital counterparts:*** New forms of computing and communication infrastructure to stream high-fidelity data from everything in a factory-floor to virtual factories in the Industrial Metaverse.

(3) ***Massive AI based simulation of In-Factory Operations:*** We need AI based methods to procedurally generate humans, machine/factory assets and be able to predict motion and dynamics based on historic and real-time actions. This is necessary to reduce overhead on having to stream everything from the real world.

(4) ***Dynamic Factory Illumination, Shading and Reflections in Machines and Factories:*** Shading and Reflection on floor, ceilings, inside and outside of machines is critical to make factories and its operations seem real. These details must be rendered in real-time as data from the physical asset streams in, to enable human users of the virtual assets to gain a realistic understanding of the as-is state of the physical factory.

(5) ***Physics of Addition & Subtractive Process System:*** Multi-scale modeling and real-time prediction is critical to make simulations of physical manufacturing process operations valuable to predict future states of processes in the physical world. New modalities of computational models must be developed to run at the time-scales of process operations.

(6) ***Temporal Super-Resolution of Virtualized Geometry:*** As humans virtually gaze and move around *meta*-verse factories, algorithms can temporarily generate super-resolution detail and texture within the field of sight to make objects in cyberspace to be as real as the physical setting.

(7) ***Procedural Audio-Generation and Smell-Generation for Factory Meta-Sounds & Meta-Smell:*** We need the technology to generate machine sounds based on the action that machine assets in the factory floor performs in the real world. Factories cannot seem real unless the sounds and even the smell of factories are perceived as real.

(8) ***Next Generation Meta-Worker:*** Workers in the physical world must be emulated in the virtual world. Wearable non-intrusive sensors placed on real workers can be used to inform synthetic models of these workers to collect worker movement and operations in the cyberworld. These can be used to predict unsafe ergonomic effects of their real-world operations and measure worker productivity.

(9) Scalable Asset Generation and Infrastructure Operation: Building Virtual Assets must be economically viable through plug-n-play type virtual infrastructure generation. Machine asset vendors must play an active role in making assets available and interoperable. A platform architecture is necessary to ensure scalability among various assets in a virtual factory.

(10) Factory Operating System Architecture: Alternate factory information systems / operation technology (IT/OT) architecture must be formalized to enable the constant communication and link-up with virtual factories to enable seamless collaboration and quality of service level delivery to its end-users.

3. Potential applications of 'Unreal' factories

3.1. 'Unreal' factories for manufacturing process education

Delivery of manufacturing training at all levels from technicians to engineers can greatly benefit from the use of 'Unreal' factories as educational tools. Students, particularly the younger generation, would not be limited to the equipment and machinery their school or university can afford. They would have the opportunity to learn about controlling nearly any piece of industrial equipment made available in the virtual space. Popup guidance displays for training purposes, multi-scale views of live operations, and the ability to control the rate of time, experiment with 'what-if' scenarios are just some example possibilities. There would be substantial benefits to the field of research. True-to-life research experiments and tests can be run in these virtual environments; for instance, material characteristics that do not exist at this time could be tested to determine what would be required for given events. The generated data could be used to justify running the experiments before investing thousands of dollars into a real-life test.

To demonstrate the potential of 'Unreal' Factories built, a prototype was built using the Unreal Game Engine 5 platform [9], a CNC machine and its operation was rendered in real-time to demonstrate a simple cutting operation. The demo features a fully modeled HAAS UMC 500 running a real-time simulation and visualization of a face machining operation. The outcome was to explore the feasibility of creating a working simulation that looked believable, with a high level of fidelity compared to other digital twins through existing technology platforms. The work required creating a library of modular materials, material functions, and particle systems to work in tandem in a physically based rendering workflow. This resulted in a visualization of the machine complete with physically simulated coolant flow and animated drops of liquid on all affected surfaces (Fig. 1.).

3.2. 'Unreal' factory collaboration across geographical boundaries

The digitalization of existing collaborative workflows has the potential to improve manufacturing process development across multi-disciplinary teams located worldwide. Aerospace manufacturers are integrating the digital twins of their products into production and assembly, by accurate virtual representations of product and process through the Industrial Metaverse. This can be significantly accelerated by the use of modular virtual machine and factory models through high-fidelity simulations. In addition to the virtual representations, Unreal factories feed information to the 'digital thread' of the product, which has two primary uses: (i) To create the feedback loop between manufacturing process within a factory and product design, and (ii) To maintain a single source of truth containing real-time communication and updates related to the product. The virtual simulations and the underlying data model has the capacity to ensure easier worldwide collaboration. The creation of the Metaverse Standards Forum [10] provides an opportunity to integrate existing manufacturing standards with the glTF and USD graphics standards for regular-use industrial applications. The expected participation of manufacturers with broadly the same vision as the IT companies leading the surge is critical to this endeavor. Over the next few years, these efforts are expected to create a convergence of ideas between developers and users of IT/OT systems, resulting in an interoperable framework with the ultimate goal of creating new feedback loops and improving productivity.

3.3. 'Unreal' factory playback for product traceability, audit & compliance

Machine to machine communication provided by IIoT enables self-learning and reinforcement learning mechanisms. An inspection station can share the results of the process to a unified namespace and supervisory QA system. This system commands the acting device (CNC machine tool, 3D-printer, extruder, etc.) to adjust the working parameters to meet the QoS (quality of service) standard levels. Additionally, it is possible to playback the operation and "dive-into" the process to see what had happened back in time. Large manufacturing integrators can audit-check lower tier manufacturers in the supply chain for compliance without physically visiting the facility. They can inspect the processes and their parameters at any given time by accessing only the Virtual Factory twin of their suppliers. There will be no need for the expensive and exhausting work trips to review documentation and verify compliance. In addition, two-way communication from virtual twin counterparts can be easily transmitted to the physical asset, enabling the machines to react faster to the demands of their customers.

4. Summary

Real-time rendering of the as-is state of physical factories to be rendered in real-time online can enable significant cost-savings for manufacturing companies in terms of savings realized by enabling virtual collaboration, virtual audit/compliance checking, manufacturing operation playback and a realistic training scenario for the future of workforce training and skills development. Ten technology developments are outlined to enable a tighter integration between physical and virtual assets. These developments would also be necessary to enable 3D model visualizations of digital twins of factories to feel more 'real', as opposed to low-resolution, cartoon like and often lagged simulations of current factory operations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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