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Digital Twins Part 1: Introduction

Introduction

A digital twin is a virtual representation of a physical product that is paired with that physical product over the course of life-cycle management to help it develop from a concept to a prototype to its final version. The term was coined by Michael Grieves and John Vickers in 2003; since then, the concept has been broadly accepted and applied in many fields, to the point that it was listed as a key strategic technology trend in 2019 by Gartner, a technology research and consulting company.[*] This development is largely driven by advances in technologies such as Internet-of-Things (IoT), multi-physical simulation, real-time sensors and sensor networks, machine learning, artificial intelligence, big data, data management, and data processing. This article is an introduction to the concept of digital twins. A follow-up article will explore challenges and technologies that enable digital twins in greater detail.

Background

A complete digital twin consists of a physical entity, its virtual representation, and the bi-directional information flow between the two. The physical entity sends its operation status to the virtual representation, which evaluates the status and sends operation adjustment requests back to the physical entity. The bi-directional information flow that bonds the physical and the virtual entity distinguish digital twin technology from traditional computational modeling and simulation, which only create virtual representations of the real world. More hardware and software technologies are required for a digital twin system, especially when it is applied to a complex facility comprised of multiple interrelated physical entities. All components in the real world and in the virtual world need to accommodate information flow through the entire system. The following elements are all necessary for digital twins:

Real world: Distributed sensors should be installed in the real world to continuously collect data for all physical entities, and these physical entities be controlled remotely by commands sent by computational models in the virtual world. Real-world sensor health should be monitored to assure the accuracy of collected data.

Virtual world: In addition to acting as a virtual simulation of the real world, the virtual world should be able to “understand” the status of the real world and provide executable solutions to optimize its real-world counterpart.

Bi-directional communication: Depending on the application, near real-time data collection and transmission and online data quality control and quality assurance should be established so that any data quality issues can be identified and solved quickly.

Data storage: Although not a required component for a digital twin system, a database of historical real-world sensor data is beneficial, as it helps reveal the root cause of malfunctions in physical entities and predict the system’s future health.

Applications

Digital twin applications in industries such as aerospace, medical, oil and gas, and electric power include:

- **Asset Performance Management,** which evaluates assets that age over time due to operation and fatigue, stress, chemical oxidation, and other factors. A digital twin uses a collection of high-fidelity, physics-based computational models and advanced analytics to transform asset data into actionable intelligence to identify issues before they occur and increase service availability. This helps reduce downtime and extend asset life while still balancing maintenance costs with lower operational risk.
- **Operations Optimization,** which delivers enterprise data visibility across the board and provides a holistic understanding of operational decisions that can expand capabilities and lower production costs. A digital twin will empower operators and plant managers with Key Performance Indicator (KPI)-driven insights to raise overall productivity.
- **Business Optimization,** which reduces financial risk and maximizes the potential for greater profitability using intelligent forecasting for smarter business decisions.

Conclusion

Over the past twenty years, the digital twin has evolved from a product life-cycle management concept into a variety of well-developed technologies that benefit many industries through applications like intelligent asset performance management and operations optimization. Current applications of digital twins are replacing humans in the traditional human-machine model with a data-driven self-learning intelligent system. By leveraging machine learning, artificial intelligence, big data technologies, and advanced sensor technologies, digital twins will likely become key technology for many industries to increase system performance and operational optimization.

Additional Reading

David Jones, Chris Snider, et. al., Characterizing the digital twin: a systematic literature review, CIRP Journal of manufacturing science and technology, 29(2020) 36-52 (DOI: 10.1016/j.cirpj.2020.02.002).

Aiden Fuller, Zhong Fan, et. al., Digital Twin: Enabling Technologies, Challenges and Open Research, IEEE Access, Aug. 2020 (DOI: 10.1109/ACCESS.2020.2998358).

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