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Digital Twins Part 2: Enabling Technologies and Challenges

Introduction

Part 1 of this article series, published last month, briefly introduced the concept of digital twin technology, along with its background and application. In this month's continuation, we will discuss various enabling technologies for digital twins and the challenges associated with them.

Enabling Technologies

Artificial Intelligence (AI) and Machine Learning (ML): Today's virtual representations of the real world have shifted from analytical modeling to data-driven modeling due to the rapid advancement of AI/ML techniques. Compared to scientific theory-based analytical modeling, which describes specific physical processes in explicit mathematical equations, AI/ML applies general mathematical models to solve a wide range of problems. For example, AI/ML modeling can fit an artificial neural network to a specific physical process by adjusting the model parameters through training data sets. AI/ML techniques provide effective data-driven tools for quick modeling of complicated physical processes and are well suited for creating digital twins of real world, complicated processes.

Cloud Computing: Cloud computing is the delivery of IT resources, such as data storage, computing power, networking, or software, over the internet, which allows access to these resources at a reduced cost. This enables digital twin systems to be implemented more economically and without the delays typically incurred by building such infrastructure within an organization.

Internet of Things (IoT) and Smart Sensor: The advancement of microchips and communication technology has enabled various physical devices to exchange data directly through internet, which now constitutes an IoT that connects billions of devices. IoT significantly simplifies the connection between physical entities and their virtual representations. Smart sensors are an important IoT component that integrate conventional sensor technology with microprocessor(s) and/or a wireless communication unit(s) within the sensor; this enables accurate and automated collection of environmental data.

Virtual Reality (VR) and Augmented Reality (AR): VR enables human interaction with a computer-generated 3-D visual environment. AR overlays computer-generated data and images over real-time captured video or images. When used together, VR and AR provide a powerful human interface for physical-virtual twins. VR/AR technology allows users to monitor critical data and operate equipment using virtual interfaces.

Challenges

As innovative and promising as the available technologies are, there are several challenges that those looking to implement them should know about. It is critical to try and counteract these issues for digital twins to be robust and beneficial. The following include some notable challenges as well as ways to try and address them.

Robustness of AI/ML models: There is a lack of effective guidance on selecting AI/ML models and determining the model's structure (e.g., the number of layers of a neural network). The best way to address this is conducting a thorough search for the best solution out of multiple options; techniques like Bayesian optimization can improve the efficiency of the search process. The performance of a trained AI/ML model could also be highly dependent on the training data and changes in the real world, such as device upgrades or seasonal weather changes. Furthermore, AI/ML models could be sensitive to missing data or outliers, which would further affect the generation of reasonable output. Applying reinforcement learning can improve a model's adaptability and the employment of ensemble methods will enhance the resistance to partial data loss.

Reliability and Security of IT Infrastructure: IT infrastructure could become vulnerable to failures and external attacks as it scales up in users, connected computers, and distribution across geographical areas. Both administrative policies and technical measurements, such as firewalls and failover systems, must be implemented to secure the entire IT system.

VR/AR Errors: Technical glitches are inevitable with VR/AR technology, since it heavily depends on image recognition and other enabling AI technologies. VR/AR errors may take a longer time to notice because of confusion between the real-world status and the VR/AR-generated virtual effect. Implementing state-of-the-art image recognition technology, additional checks of critical operations, user training, and test performance would help reduce error rates.

Software/Hardware Upgrade: As a digital twin system integrates software and hardware developed by different parties, component upgrades may affect the entire system. For instance, a software application could stop working after an upgrade to a third-party package. Reducing the number of service providers and the frequency of software/hardware updates and performing rigorous testing after each upgrade are practical solutions.

Conclusion

A variety of computational solutions and hardware technologies are available to support robust digital twin development. However, users who are looking into enabling technology should be conscientious about what technology they implement and thorough in their research, system design, and management. While digital twins can lead to significant improvements in performance and productivity, successful implementation must consider reliability, safety, security, and other management issues.

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).