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Core Technologies for Digital Twins

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ABSTRACT

Digital Twin (DT) technology is revolutionizing industries by creating virtual replicas of physical systems, enabling real-time monitoring, predictive analytics, and performance optimization. At the heart of DT lies a combination of advanced technologies that work together to ensure its effectiveness. This paper explores the core components of DT, including the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Big Data Analytics, Cloud and Edge Computing, and Cyber-Physical Systems (CPS). IoT plays a crucial role by collecting real-time data from sensors and connected devices, forming the foundation for DT applications. AI and ML then process this data, allowing systems to make intelligent decisions, detect faults, and improve efficiency. Big Data Analytics further enhances DT capabilities by handling vast amounts of structured and unstructured information, extracting meaningful insights for better decision-making. Cloud and Edge Computing support DT operations by providing scalable storage and processing power, ensuring both accessibility and real-time responsiveness. Meanwhile, CPS bridges the gap between the physical and digital worlds, enabling seamless communication between them. Beyond these core technologies, DT relies on advanced modeling techniques, including physics-based simulations and data-driven models, to create accurate digital replicas. Standardized communication protocols and interoperability frameworks are also critical in ensuring seamless integration across different systems. At the same time, cybersecurity measures and data privacy strategies are essential for protecting DT applications from potential threats. The use of DT is expanding across industries such as manufacturing, healthcare, smart cities, and energy, showcasing its potential to drive digital transformation. However, challenges remain, including high implementation costs, computational complexity, and integration difficulties. Overcoming these obstacles requires ongoing technological advancements and collaboration between researchers, industry professionals, and policymakers to establish standardized frameworks and ensure scalability. This paper provides a comprehensive overview of the key technologies that power DT, examining their roles, interactions, and future directions to enhance adoption and effectiveness across various sectors.