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Intelligent digital twin for energy industry in AIoT networks

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Abstract

After industrial revolution the demand for the capacity and reliability of optical networks has continued to grow. Industries have become sources of numerous heterogeneous data. In order to handle these data/challenges, many issues need to be resolved, among which the low-margin optical networks design, power optimization, routing and wavelength assignment (RWA), failure management are quite important. Today Artificial Intelligence (AI), especially Machine Learning (ML), Digital Twins (DT) are regarded as one of the most promising methods to overcome the errors/problems that occurred at site. Intelligent systems make it possible to predict the behavior of highly complex production systems. Internet of Things -IoT- represents a new production reality. In the study interviews with experts on "Intelligent digital twin for Energy Industry in AIoT networks" are performed and Fuzzy MCDM based approach is developed. In the study 6 main criteria, i.e., Process Monitoring and Resource Optimization, Advanced Analytics, New Opportunities, Intelligent Grid, Cost-savings and Data Management, Sustainability and 34 related sub-criteria are evaluated by experts. Active digital twin is a solution that is carrying out a certain task on behalf of an object or under user assignment. Such form of digital twin is called intelligent information agent since it is already equipped with a certain form of artificial intelligence. It uses sensor devices and gateway connectivity to derive actionable insights and use them to develop new and advanced services for enhanced productivity.

Introduction

The Internet of things (IoT) describes physical objects (or groups of such objects) with sensors, processing ability, software and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks. IoT has had a significant impact on manufacturing, energy, agriculture, transportation, and other industrial sectors. The Industrial IoT (IIoT) is an industry-specific variant of the IoT, which provides an impressive potential for businesses via connected machines, sensors, and applications. It is one of the most exciting technologies now reshaping industrial enterprises, prompting them to modernize their processes, system intelligence, and facilities in order to cope with emerging disruptive technologies. IIoT improves manufacturing efficiency, safety, scalability, production time, and profitability in the industrial sector.

Recent advances in 5G & 6G-technology and IoT technology provide cost-effective approaches for wireless network connectivity between various sensors and processors in both industrial and commercial development. Wireless and portable electronics are undergoing explosive development, which is considered as a promising technology. In this regard, the application of various sensors makes it possible for the IoT sensor system to real-time collect data and transmit the sensor information to the cloud server using big data and artificial intelligence (AI) analysis. Therefore, a new data-driven product design model has recently emerged, which would make the design process more digitalized than ever before. Many studies have focused on the synergy between virtual reality (VR) and physical reality. In the physical world, the user's performance, behavior, and interaction with the other users will be captured by the sensor, and the actuators in the system will realize the feedback with the user. In the virtual world, the cloud will create corresponding virtual objects to visualize the structure of the object to better simulate the behavior of using the object. Traditionally, the construction, analysis, and upgrade of virtual and physical objects will be separated from each other with a lack of a unified integrated analysis. Therefore, a new framework is needed in view of the data-driven product design, which can effectively realize the fusion and integration of various sensor data, hence prompting better interaction between virtual objects and physical objects. Virtual reality (VR) and augmented reality (AR) technologies are rapidly developing, which opens the door for a diversified range of applications in entertainment, virtual communities, personal healthcare, industrial design, surgical training, and many others.

The emerging "Industry 4.0" concept is an umbrella term for a new industrial paradigm which embraces a set of future industrial developments including cyber-physical systems (CPS), the Internet of things (IoT), the Internet of services (IoS), robotics, big data, cloud manufacturing and augmented reality. Industrial processes need most tasks to be conducted locally due to time delays and security constraints, and structured data needs to be communicated over the internet.

The Industrial Internet of Things-IIoT, is among the advanced manufacturing technologies collectively referred to is Industry 4.0, or the Fourth Industrial Revolution. Transforming the energy sector with IoT technology is an innovative way to promote improved productivity and recognize/arrange the consumption patterns to cut-short the excessive energy usage. In the energy sector, IoT devices have been able to create intelligent networks, i.e. Smart Grids, through the collection, transmission and use of large quantities of data. In this way, it integrates in an intelligent manner all of the assets connected to the network, optimizing operation and increasing the flexibility of the systems.

Transforming traditional factories into Smart factories via Smart Grids requires well-planned investments in advanced technologies such as IoT, AI and Digital Twin. Digital Twin Technology can help us to achieve Smart Factory by accelerating smarter decision making and autonomous operations, which reduces the time and cost associated with assembling, installing, and validating the factory's newer production process.

Digital Twin technology provides tools for the virtual representation of the potential new product design or production process. It plays a vital role in evaluating the product ideas before invest and adoption. A Digital Twin based Software Platform facilitates factories with digital footprints of physical products, which empowers organizations to predict outcomes precisely, detect physical issues, and develop efficient products.

What is Digital Twin?

David Gelernter was the first to mention the idea of digital twins in his book "Mirror Words" in 1991. But the concept and model of digital twin technology were first introduced publicly at a Society of Manufacturing Engineers conference by Dr. Michael Grieves in 2002. The Digital Twin platforms mirror the physical system, keep track of the real-time status, and keeps a complete record of the evolution a physical entity goes through.

The digital twin, as a further realization of VR and AR technology, was first practically defined by NASA in 2020 to improve physical model simulation for building the spacecraft. Digital Twin technology utilizes the historic product data to create futuristic simulations that further predict the capabilities of the Potential product or service. Digital Twin platforms incorporate multiple advanced technologies such as Artificial Intelligence, the Internet of Things, machine learning, and many more. There are Four types of Digital Twins: Parts Twining, Product Twining, System Twining, and Process Twining

In the past few years, digital twins have been put forward more in the concept of IoTs, which refers to the creation of a digital simulation in the information platform by supplementing AI, machine learning (ML), and software analysis. This simulation will be automatically modified accordingly based on the feedback from physical entity variations. The design of digital twin should be more dedicated to exploring applicability, that is, communication, collaboration, and coevolution between physical products and their digital representations (virtual products), toward more informed, expedited, and innovative design processes. With the help of various types of sensors, the realization of the digital twin has wider applications ranging from satellites, manufacture, to smart homes. After integrating enormous sensors with diversified functionalities distributed around the physical scene, the digital twin will form a virtual environment capable of monitoring the physical products and being managed via the IoT. Therefore, the development of various sensors is significant for the future realization of the digital twin. Currently, the sensors successfully applied in smart homes can be divided into the control interface of household appliances (e.g., voice control and self-powered interface control), environmental monitoring (e.g., gas leakage detection), and human activity tracking.

Microelectromechanical system (MEMS)/nanoelectromechanical system (NEMS), as the most commonly used micro-sensing devices, can convert various physical changes, such as humidity, lightness, temperature, pressure, motion, and acoustics changes into the changes of electrical signals. Therefore, MEMS-/NEMS-based sensors have always been an important part of wireless sensor networks. Notably, the wireless sensor network would require a large number of batteries to power those massive and distributed sensors. Therefore, it is very important to establish a sustainable wireless IoT sensing system by developing energy harvesters and self-powered sensors based on specific scenarios.

Material and Method

In the study; an integrated Fuzzy AHP- Fuzzy TOPSIS- Fuzzy VIKOR approaches are used to assess/evaluate Intelligent digital twin for Energy Industry in AIoT networks. In literature Fuzzy Multi Criteria Decision Making Methods (FMCDM) are used in different fields by many researchers [1-23] by using MATLAB program.

The study, i.e., "Intelligent digital twin for Energy Industry in AIoT network", measuring scale, consists of 6 dimensions-main criteria and 34 evaluation factors-sub-criteria are evaluated by decision makers (DMs). A questionnaire was developed following the methodology proposed for the below methods, which was answered by 29 experts/DMs.

Active digital twin is a solution/software that is carrying out a certain task on behalf of an object or under user assignment. Such form of digital twin is called intelligent information agent since it is already equipped with a certain form of artificial intelligence (AI). It uses sensor devices and gateway connectivity to derive actionable insights and use them to develop new and advanced services for enhanced productivity. It further improves real-time decision-making, complex operability, and overall experiences.

1. Process Monitoring and Resource Optimization: Using sensor devices in a power plant offers automated execution of the processes and render better services that are mostly error-free. IoT technology is a smart concept that also protects excessive resource utilization and helps maintain consistency. IoT allows smart process monitoring that gives every detail of the plant-process in the form of data.

2. Advanced Analytics: Sensor-based functioning of the power industry is bringing a revolutionary change. It uses advanced techniques to fulfill the business requirements and generate quality production. The industrialists are making the most out of using advanced analytics with their business. It uses sensor-enabled data to extract information from the assets and make better decisions than before. Data analytics helps the power sector to optimize generation and planning.

3. New Opportunities: IoT brings new business opportunities along with newer and advanced concepts. It involves sensor devices, gateway connectivity, and communication protocols that combine and form IoT architecture for multipurpose businesses. One can use IoT technology to avail business benefits and enable smart techniques for better productivity and growth. IoT is a futuristic technology, which empowers businesses through its real-time monitoring features, smart data management, and analytics.

4 Intelligent Grid: IoT provides a smart grid system to get control over the power flow or curb the energy consumption at significant levels. It further curtails the energy load to match the real-time generation or near real-time. IoT is an automated concept that offers a cost-effective approach to interconnect the users for effective power usage.

5. Cost-savings and Data Management: IoT in the energy sector is an advanced process that includes planning and energy management of the consumption patterns in multiple domains. It allows the managers to take complete control of energy data from scratch and optimize the process significantly. Using an IoT-powered solution in the energy sector utilizes sensor-based methods to establish the automated functioning of the industry.

6. Sustainability: All assets/machines/equipments have been made to talk to each other through IoT. The energy sector is the major driver of accountability that seeks smart ways to reduce environmental issues. IoT facilitates automated maintenance and reporting, optimization of smart grids, renewable energy generation, and measure carbon consumption in real-time. The technology is enabling sustainability around the industrial world through its smart techniques and is allowing the managers to make informed decisions for better business growth.

Internet of Things B2B

Internet of Things B2B solutions account for the majority of economic value created from IoT to date. In B2B settings, i.e., marrying IoT and AI can improve the predictive-maintenance capabilities of machines, while also empowering service providers to watch the health of their assets in real time, proactively addressing issues before a bigger breakdown occurs. B2B applications have grown faster than expected, particularly given the adoption of factory-automation solutions. However, through 2030, B2B applications are projected to nonetheless account for 62 to 65 percent of total IoT value. IoT provides the stated advantages; improved operational efficiency, better product quality and services, detail-oriented decision-making, cost-efficiency and increased Return on Investment (ROI), unlimited scalability, remote machine monitoring, accurate asset tracking, reduced power consumption, packet-switch services, real-time monitoring, time tolerance and control, geo-fencing, continuous data transfer, predictive maintenance.

Results

Sensor technology, big data and analytics are used to optimize operations, such as efficiently balancing supply and demand as customers connect to a smart grid. The usage of IoT in energy production helps to satisfy the energy demands in smart cities in an efficient way. However, a robust digital infrastructure is crucial for the roll-out of an architecture of connectivity and data.

The study, i.e., Intelligent digital twin for Energy Industry in AIoT network, i.e., measuring scale, consists of 6 dimensions-main criteria and 34 evaluation factors-sub-criteria are evaluated by decision makers (DMs). A questionnaire was developed following the methodology proposed for the below methods, which was answered by 29 experts/DMs.

After acquiring the fuzzy comparison matrices, importance weights of "intelligent digital twin's" dimensions; evaluation criteria is calculated by using Fuzzy method. According to the calculated criteria weights for "intelligent digital twin's" weights; the most important evaluation dimension/main-criteria is "Cost-savings and Data Management", the second important evaluation dimension is "Process Monitoring and Resource Optimization" and the third important evaluation dimension is "Advanced Analytics".

Conclusion

"Industry 4.0" concept has the flexibility to achieve interoperability between the different industrial engineering systems. To connect the different industrial equipment and systems, the same standards and safety levels are required. The "Industry 4.0" concept was born to apply the ideas of cyber-physical systems (CPSs) and IoT to industrial automation and to create smart products, smart production, and smart services. It involves cyber-physical systems, IoT, cognitive computing and cloud computing and supports what has been termed "smart factory". IoT technologies offer greater availability of information throughout the chain of value, allowing for amortization of better tools for decision making. IIoT is used to transfer the data from systems that monitor and control the industrial equipment to data processing systems that cloud computing has shown to be important tools for meeting processing requirements by using Wi-Fi, radio, satellite or cellular networks.

The growing integration of AI with functional electronics has spawned a new breed of intelligent systems capable of detecting, analyzing, and making decisions using machine learning algorithms. In addition, through the high transmission rate of 5G & 6G networks, the collection rate of the sensor data can meet the requirements of big data analysis and higher forms of AI. At the same time, the artificial intelligence of things (AIoT) as a combination of AI and IoT has become the most advanced technology, which can realize an intelligent ecosystem in a wide range of applications. When various sensors are combined with AI technology, the resulting intelligent systems can perform more complex and complete analysis on the gathered data sets than traditional methodologies. The accuracy of prediction can be increased by selecting appropriate algorithms, fine tuning algorithm parameters, and combining various types of data from different sensors. Digital-twin based intelligent systems have the potential to revolutionize the way we sense and interact, with applications as diverse as enhanced identity recognition, personalized healthcare monitoring, rehabilitation, robotic control, smart building, and encrypted interactions in VR and AR space.

Digital Twins is a technology that can synchronize digital environments with physical environments and reflects any changes that happen with actual products. The blend of Smart Manufacturing and Digital Twin Technologies can radically revise product designs, product manufacturing, usability, maintenance, and other aspects of manufacturing. Digital Twin Platforms enable factories to achieve Smart Factories with enhanced manufacturing planning and detailed production. The usage of digital twin boosts the achievement of the Smart factory. In line with the digital twin and smart manufacturing propels easy and accurate transformation of the traditional factory to the Smart Factory.

The application of AI will bring process automation and process optimization to a new level, due to its ability for inaccurate feature classification and prediction of sensor data, efficient processing of massive and dimensional datasets, and multimodal physiological signal analysis. Intelligent systems also make it possible to predict the behavior of highly complex production systems. On the other hand, digital twin-based intelligent systems will promote and fascinate the smart future.

The importance of the technology of digital twin as his significance stems from its simultaneous double benefit as a simulation and controlling tool. Creating virtual replicas of manufacturing flows, the whole factories, enterprises or supply-chains via passive model of digital twin enables enterprises to monitor, simulate and test established as well as hypothetical processes.

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