https://rijournals.com/biological-and-applied-science/

RESEARCH INVENTION JOURNAL OF BIOLOGICAL AND APPLIED SCIENCES 3(3):30-33, 2024

Online ISSN: 1115-6171

Print ISSN: 1597-2879

Integrating AI and IoT for Smart Manufacturing

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ABSTRACT

Smart Manufacturing (SM) is leading the Fourth Industrial Revolution (Industry 4.0) in manufacturing. SM optimises production via Smart Products, Operations, and Factories. This article defines, explains, and applies AI and IoT to SM. AI's data-driven decision-making and IoT's real-time data interchange improve industrial systems' intelligence and efficiency. We study how smart factories may harmonise various technologies for real-time adaptation, predictive maintenance, quality control, and operational excellence. The report also analyses AI-IoT integration problems and suggests future research and implementation techniques.

Keywords: Industry 4.0, Smart Manufacturing (SM), Artificial Intelligence (AI), Internet of Things (IoT), Smart Factories (SFs).

INTRODUCTION

The advent of the Fourth Industrial Revolution, known as Industry 4.0, has engendered a significant transformation in manufacturing practices. A key facet of Industry 4.0 is the advent of Smart Manufacturing (SM), which synergistically integrates Smart Products (SPs) and Smart Operations (SOs) in Smart Factories (SFs). In recent years, IoT technologies, particularly sensors, have gained traction in manufacturing as a pipeline for data analytics related to SPs. In parallel, Artificial Intelligence (AI) algorithms have emerged as a tool for data-driven decision support in manufacturing. Despite the encapsulation of these technologies in a greater context of SM, a cohesive integration of their definitions and roles in SM is lacking. The goal of this paper is to elucidate the definitions of IoT and AI technologies, demonstrate how these technologies can be integrated into SM, and discuss the implications of such integration [1]. The Internet of Things (IoT) is characterized as "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities, and use intelligent interfaces to interact with other entities." IoT enables the interconnection of various devices and smart objects, thus enabling remote monitoring and control capabilities. Smart Products (SPs) are products that leverage IoT technologies to interact with stakeholders, such as suppliers and customers. IoT-enabled SPs can provide data regarding their condition, performance, and environment to other stakeholders, which can be used for data-driven decision support [2]. Artificial Intelligence (AI) encompasses systems or machines that emulate "intelligent" human-like behaviors. AI algorithms enable systems to analyze data to make inferences and generate knowledgeable output. In recent years, AI algorithms have gained traction in manufacturing contexts, particularly for data-driven decision support through the processing of data from SPs. The dataset is expected to be fragmented and heterogeneous due to the decentralization of SPs. A particular challenge for the implementation of AI algorithms in this context is data preprocessing, with several steps needed before data is ready for analysis. Data preprocessing encompasses data cleansing, integration, transformation, and reduction [3].

FOUNDATIONS OF AI AND IOT

Artificial Intelligence (AI) and Internet of Things (IoT): Definitions, Characteristics, and Core Technologies

Artificial Intelligence (AI) refers to a computer system's capability to perform cognitive tasks that characteristically require human intelligence, such as perceiving, reasoning, learning, and planning.

Industry representations of AI often project a future world dominated by socio-technical systems for the automatic generation of networks of computers and robots, all of which will be outfitted with "intelligent" decision-making software. However, here, AI is defined more modestly, as a computer system that can evaluate the surrounding world using sensors and make decisions depending on the evidence. AI technologies include machine learning, natural language processing, speech recognition, neural networks, and so on [4]. According to IoT World Forum, the Internet of Things (IoT) is the connection of everyday objects to the internet, facilitating easy monitoring and controlling. IoT applications in an industrial context are called Industrial IoT (IIoT). As with AI, IIoT is often presented overly positively in industry technical literature and market analysis and predictions. State-of-the-art IIoT technologies and solutions include smart sensors, smart object representational ontologies, service-oriented software architecture, and cloud-based service mathematics [5].

Generational characteristics of AI and IoT Technologies for Smart Manufacturing

As highlighted in Figure 1, AI and IoT technologies should arguably be understood as constituent components of a smarter generational development, rather than solely as underlying core technologies. More precisely, they represent a conceptual transition from the second, fixed, and localized generation (SFM2.0) to the third, networked and dynamically flexible, generation (SFM3.0) of factories. In SFM2.0, the capabilities of sensors, robots, and machines are internally represented by shared ontologies and models. They are fixed prior to a batch of production or a production line's design phase. Computer simulations of the digital model are used for design optimization and re-design for changes in external conditions, such as varying production volumes or new product types [6]. SFM3.0 moves towards dynamic representations for decision-making, using learning-based approaches. Smart objects in factories 3.0 generate continuous, real-time data streams. AI uses this data to develop local knowledge for situation awareness. Objects should share this knowledge with peers for a broader understanding. The shared data allows factories with SFM3.0 to make informed production decisions. (313 characters) [7].

APPLICATIONS OF AI IN SMART MANUFACTURING

The application of artificial intelligence (AI) in industrial Internet of Things (IIoT-based smart manufacturing is an active area of research, helping organizations to utilize data and enhance value-added services. The advance in communication technology has made it possible to equip manufacturing machines with sensors and collect data. This collected data can be utilized for predictive maintenance, quality prediction, process selection, collision avoidance, repair action recommendation, etc., using different AI techniques (machine learning, deep learning, reinforcement learning) [8]. The manufacturing sector is adopting IIoT-driven smart manufacturing to advance industrial automation and competition. The use of smart sensors, smart machines, and wireless communication devices facilitates the data exchange between machines, workstations, and management information systems. Artificial intelligence (AI), a part of the development in Industry 4.0, allows the automation of the manufacturing environment. The historical process data of the industrial setup can be utilized for manufacturing applications using different AI techniques and models. The literature has been reviewed to present the various applications of AI in IIoT-based smart manufacturing. Applications like predictive maintenance, fault identification, quality prediction, process selection, and others have been categorized, and the work of the researchers has been summarized [9]. The smart factory comprises several smart machines with sensors and computer systems. These smart machines collect the manufacturing process data to detect faults in real-time, generate alarms, and store them in the database or cloud. Predictive maintenance (PdM) aims to upgrade the condition-based monitoring of the machine and reduce unintended failures. The remaining useful life (RUL) of the machine can be estimated using machine learning and other techniques from the condition monitoring information. Various researchers have worked on this application, and their efforts have been detailed. Time-series analysis of industrial data for various manufacturing processes has also been presented. Fault detection, alarm generation, and collision avoidance initiative have also been reported in recent works [10].

APPLICATIONS OF IOT IN SMART MANUFACTURING

The Internet of Things (IoT) is extensively utilized in smart manufacturing processes, with numerous applications contributing to improved productivity, streamlined operations, and safer environments. This discussion focuses on several noteworthy applications of IoT in smart factories [11]. IoT is employed in smart factories to enable machine-to-machine communication, allowing for precise, real-time data. This technology provides manufacturers with valuable insights, ushering in a new era of intelligent manufacturing driven by impactful testing, analysis, prediction, and recommendation technologies. Sensors in manufacturing facilities gather data from machines, while centralized data platforms track the data and analyze it to form recommendations. By automating or reforming operations based on these recommendations, factories benefit from low operational costs, high equipment reliability, and reduced production disruptions [12]. Conditions can be monitored and controlled remotely, assisting operators in making maximum production quantity decisions. Smart dust, a development of tiny, wireless sensors, accumulates information on temperature, pressure, and humidity for condition recognition. The data is analyzed, local maintenance activities are scheduled if necessary, and corrective or preventive measures are suggested [13]. The Industrial Internet of Things is composed of interconnected physical devices that compile and analyze massive amounts of data. The technology can detect production volume, defects, and labor efficiency, as well as notify operators and engineers of potential problems. Intelligence assessment models adopted by industries improve productivity and quality, focusing on evaluating aspects of decision-making, business intelligence, and equipment monitoring [14]. Warehouse management is improved through smarter systems featuring RFID tracking capabilities for palletized products, producing real-time views of stock levels and modern systems solving congestion issues. IoT-powered smart meters improve energy efficiency and reduce operational costs by gathering data on consumption patterns. Smart supply chains predict delays, allowing manufacturers to take corrective actions and minimize losses [15].

INTEGRATION OF AI AND IOT IN SMART MANUFACTURING

Over the past decade, AI and IoT have gained popularity in various applications. IoT uses sensors, smart devices, cloud storage, and the internet to exchange real-time data. AI enables intelligent behavior through real-time data analysis using algorithms like machine learning. AI and IoT have been integrated in domains such as agriculture, healthcare, transportation, stock market, and smart cities. Smart manufacturing (Industry 4.0) offers an opportunity to transform the industry with AI and IoT. It combines manufacturing processes with communication and information technologies to create efficient and high-quality smart factories. AI and IoT in smart manufacturing enable real-time adaptability and optimization. Smart devices are interconnected through IoT platforms for information exchange. AI optimizes processes and includes fault detection and feedback control. Unsupervised learning is used for data analytics [16].

CONCLUSION

The integration of AI and IoT in Smart Manufacturing marks a significant milestone in the evolution of the manufacturing industry. AI enhances the processing and analysis of large datasets generated by IoT devices, enabling real-time decision-making and optimization in production processes. The fusion of these technologies results in more adaptive, efficient, and intelligent manufacturing systems that can predict maintenance needs, improve product quality, and reduce downtime. However, challenges such as data preprocessing, system interoperability, and the need for robust security measures must be addressed to fully realize the potential of AI and IoT in smart manufacturing. Future research should focus on overcoming these barriers and exploring new applications of AI and IoT to further enhance manufacturing capabilities.

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CITE AS: Kato Jumba K. (2024). Integrating AI and IoT for Smart Manufacturing. RESEARCH INVENTION JOURNAL OF BIOLOGICAL AND APPLIED SCIENCES 3(3):30-33.