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EXPLORING IOT-ENABLED AI SOLUTIONS: A DETAILED SURVEY FOR SMART MANUFACTURING AND CPS

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Abstract: The Internet of Things (IoT) and artificial intelligence (AI) have revolutionized cyber-physical systems (CPS) and smart manufacturing by creating new avenues for connectivity, automation, and intelligence. Real-time data collection is made possible by IoT, while advanced analytics, predictive modelling, and adaptive decision-making are offered by AI. Their convergence supports. Reducing downtime and operating expenses in smart manufacturing through quality assurance, dynamic scheduling, process optimization, and predictive maintenance. In CPS, IoT-AI cooperation enhances real-time monitoring, autonomous coordination, decision support, and human-machine interaction, thereby facilitating more flexible and intelligent operations. The most recent developments in frameworks, applications, and architectures show their growing impact on industrial digital transformation, especially in relation to Industry 4.0. This survey summarizes the state of the art, finds well-known solutions, and illustrates how the IoT-AI interactions can create scalable, sustainable, and adaptive ecosystems. Through its synthesis of key technological knowledge, the research highlights the promise of utilizing the IoT and AI as a source of future industrial development and smart environments.

Keywords: IoT–AI Integration, Smart Manufacturing, Cyber-Physical Systems (CPS), Real-Time Monitoring, Industry 4.0, Predictive Maintenance.

1 INTRODUCTION

The industrial sector is undergoing a significant transformation due to the integration of modern technologies, including virtualization, the Internet of Things (IoT), cloud computing, and artificial intelligence (AI). In order to improve decision-making and business efficiency, smart manufacturing companies nowadays are focusing more on big data, IoT, AI, and cyber-physical systems (CPS)[1]. IoT allows more sophisticated services to be implemented through establishing a link between the physical and digital worlds, and cloud computing and wireless sensors enhance data gathering and analytics[2]. Such developments enable industries to streamline their production processes, enhance production efficiency, and implement predictive maintenance measures to minimize failures and costly downtime.

The process of intelligent manufacturing can be traced through the development of mechatronics into systems that are both cyber and physical. Electrical, electronic, control, and computer engineering all come together in mechatronics, which initially promoted automation but had a very high cost and lacked cross-disciplinary skills [3]. To address these issues, CPS became one of the pillars of the paradigm in the 20th century. CPS combines physical machinery and digital intelligence, leveraging its fundamental elements—sensors, actuators, and controllers—to reduce operational costs, accelerate data processing, and lower overall expenses. This shift paves the way for increased IoT and AI integration across various businesses.

Industry 4.0 and the Industrial Internet of Things (IIoT) have also restructured CPS-based industrial systems. Real-time process tracking, management, and optimization are achieved by both paradigms through the use of advanced technologies like as artificial intelligence (AI), machine learning (ML), augmented and virtual reality (AR/VR), and the Internet of Things (IoT)[4]. Industry 4.0 focuses on intelligent connectivity and automation, whereas the IIoT enhances the interoperability of devices and platforms[5]. The use of AI-powered analytics and intelligent sensors demonstrates how CPS, Real-time analytics, and IoT enable predictive decision-making and sustained industrial growth.

Therefore, Industry 4.0, or the Fourth Industrial Revolution, is a paradigm change that prioritizes networked ecosystems, intelligent manufacturing, and unconventional production methods. Systems can now automatically monitor, optimize, and adjust to industrial demands thanks to the deployment of industrial 4.0, CPS, IoT, big data, and cloud computing[6]. In this context, AI is essential because it mimics human intellectual abilities, including reasoning and decision-making, which initiate automation, fault detection, and quality enhancement. Combining IoT and AI makes the manufacturing industry more resilient, nimble and efficient.

The convergence of AI, the IoT, and other immersive technologies, such as AR and VR, ultimately introduces new opportunities for cyber-physical systems and smart manufacturing[7]. This integration not only increases operational efficiency but also improves human-machine interaction by allowing adaptive, real-time, and context-aware systems. With conversational AI and advanced analytics, industries can create personalized, scalable, and intelligent solutions that strengthen the connection between physical infrastructure and digital intelligence. Hence, the combined power of IoT and AI forms the cornerstone of next-generation smart manufacturing and CPS, making it a central focus of ongoing research and industrial applications.

1.1 Structure of the paper

The paper is organized as follows: Section 2 examines the integration of IoT and AI in smart manufacturing, with a focus on Industry 4.0, architectures, and IIoT enabled by 5G. Section 3 addresses their role in cyber-physical systems, focusing on security, monitoring, and key applications. Section 4 presents the application of IoT in smart manufacturing. Section 5 reviews recent literature, outlining key findings, challenges, and opportunities. Section 6 ends with observations and suggestions for further investigation.

2 INTEGRATION OF IOT AND AI IN SMART MANUFACTURING

The manufacturing sector is being revolutionized by smart manufacturing, which integrates supply chain optimization, inventory control, predictive maintenance, personalization, and quality assurance. Predictive maintenance using sensors reduces downtime and costly repairs, and real-time monitoring improves quality control by promptly detecting flaws and making the required corrections[8]. AI in IoT sensors and data analytics optimizes inventory levels, reduces waste, and enables more personalized products. Supply chain processes are streamlined by smart manufacturing, which shortens lead times and improves delivery efficiency[9]. By automating repetitive operations, increasing productivity, and reducing the risk of human errors, the IoT in manufacturing supports smart manufacturing projects. Several processes in manufacturing facilities have been greatly streamlined in recent years by the introduction of IoT-enhanced robot systems (with precision, durability, and speed).

2.1 Industry 4.0 and Smart Manufacturing

The continuous revolution in automation and data sharing in the industrial industry is referred to as Industry 4.0. This transformation, sometimes referred to as the Fourth Industrial Revolution, is based on cloud computing, cognitive computing, the Internet of Things, and cyber-physical systems. Smart factories may assess data to anticipate failure, adjust to changes, and set up to maximize productivity by combining these technologies[10]. The aim to promote modern manufacturing technologies and processes gave rise to the phrase "Industry 4.0" in Germany. It encompasses a range of modern technologies, including industrial, automation, and data interchange. Real-time data gathering and information openness inside an organization are made easier by Industry 4.0[11]. This enables greater flexibility and decentralized decision-making. Intelligent cyber-physical systems power smart manufacturing in Industry 4.0. These are tangible assets equipped with processing facilities and network connectivity, such as industrial lines and machinery. Due to this, decentralized systems can make decisions locally and automatically. Cyber-physical systems can learn and evolve rather than be configured as they are. They self-optimize performance throughout the production plant with telemetry data.

2.2 IoT–AI Integration Architectures

The IoT-AI integration architectures act as the brain of smart manufacturing and cyber-physical systems that allow smooth interaction between data collection to processing, and decision-making[12]. These architectures involve IoT devices comprising sensors, actuators, and embedded devices that gather data in real time from industrial processes and transmit it via 5G networks or through communication protocols like MQTT and CoAP[13]. The data is processed at different layers of edge, fog, and cloud computing, with the goal of optimizing latency, scalability, and physical storage (Figure 1). At the edge and fog layers, low-latency decisions, such as anomaly detection and action-enabled equipment monitoring, are conducted. In the cloud layer, large-scale abstract analytics, predictive modelling, and digital twin simulations are undertaken. Information and actionable insights are collated into AI algorithms, especially ML and DL models, to create and determine predictive models (failure prediction, resource optimization and resilience of the system).

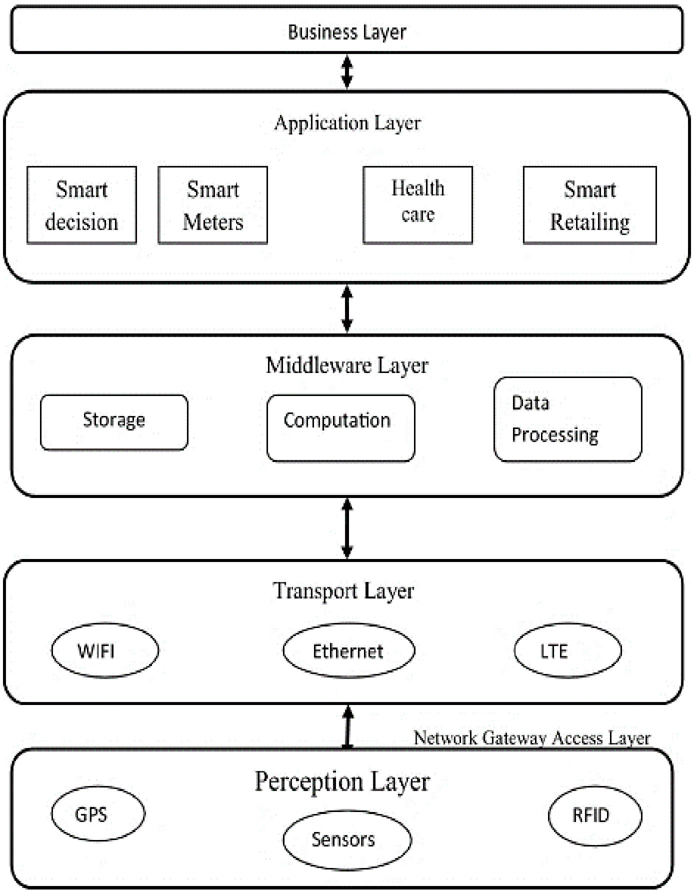

Figure 1: Architecture of Artificial Intelligence in IoT

2.3 Smart Manufacturing Process of 5G Network-Enabled Industry Internet of Things (IIoT)

The technology used to enhance CPMS in businesses determines the unique characteristics of the intelligent manufacturing process made possible by 5G network-enabled IIoT[14]. The technologies used are determined by the CPMS's capacity for improvement, the characteristics are as follows:

- There are several Internet of Things-based connections and communications between the various equipment and systems on an industrial shop floor. The shop floor is the location where production, assembling, and manufacturing take place in an industry.
- A smart industry system has to have low latency and high dependability. It also needs to have monitoring functions. These 5G network characteristics enable IIoT to enhance industrial real-time production and machine-to-machine connectivity, while also providing shop floor manufacturing processes with status information.
- 5G and edge computing increase the application's efficiency; also, real-time processing of large amounts of data is possible. 5G with SDN technology manages data transit between systems and servers with severe constraints.
- The industry can now create and manufacture high-quality virtual reality products thanks to 5G's use of 3D technology. The high-bandwidth and low-latency characteristics of 5G mobile networks were dependent on apps that utilized VR and AR.
- 5G network, which uses multi-beamforming technology to reduce the energy and cost of performing an action transformation in a communication network.

3 IOT–AI SYNERGY IN CYBER-PHYSICAL SYSTEMS

The IoT provides a wealth of information that is always accessible in the context of IoT-CPS. The SOs should possess some natural intelligence, as well as the capacity for modest local processing. However, more information is required to draw an evidence-based judgement[15]. This is when data is shared and analyzed in a decentralized fashion across several locations, utilizing the macroscopic version. Actuators can perform a variety of functions from the SO after the final decision has been sent to them, based on the combined analysis findings[16]. The data is useless if a considerable amount of time passes between data transmission and decision-making. This enormous amount of data in real-time is too significant for conventional analytical methods to completely understand. The variety of potential linkages and correlations between diverse data sources is too vast for analysts to fully comprehend by hand, even though the volume, velocity, and diversity of data are too high for thorough manual analysis.

3.1 Cyber-Physical Systems Framework

The privacy and security features of a framework using the three orthogonal coordinates of security, systems, and components can be used to depict a CPS[17]. Medical gadgets, smart grids, smart automobiles, and industrial control systems (ICS) are instances of these crucial services, and their components interact in the physical, cyber, and cyber-physical worlds. When the writers compared these facilities, they made special reference to these four elements. The system may, however, coordinate all possible services that are covered by the previously mentioned CI sectors. A CPS's security features, including controls, threats, vulnerabilities, and attacks, are addressed in the third coordinate. A visual representation of this framework is shown in Figure 2.

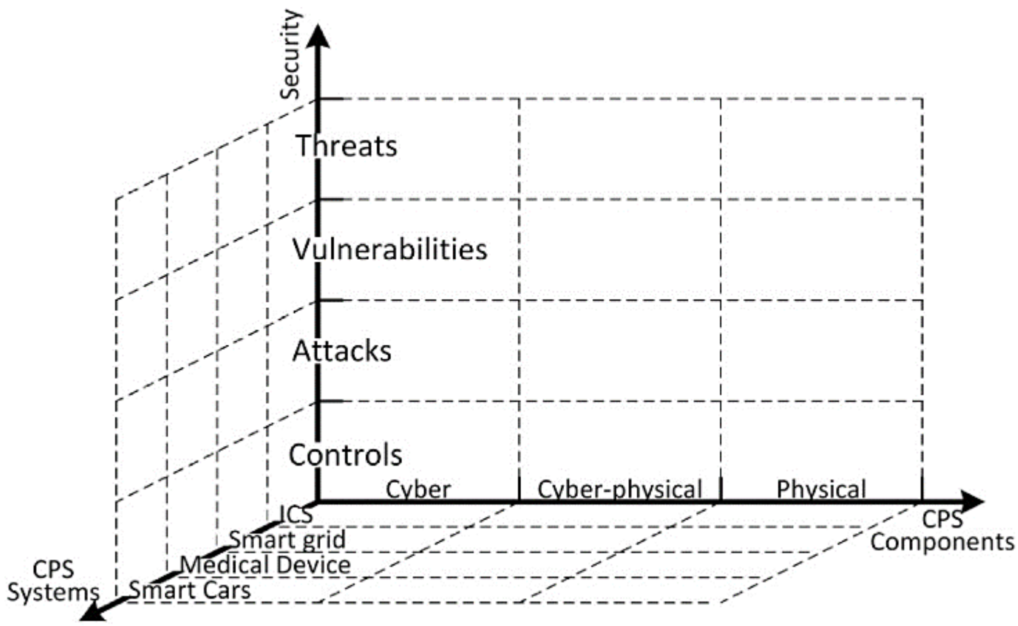

Figure 2: Abstract view of a CPS security framework

3.2 Real-Time Monitoring and Control with IoT–AI

The integration of AI with IoT enables real-time monitoring and control, which is now essential to cyber-physical systems and smart manufacturing. High-speed networks, such as 5G or LPWAN, are utilized to transfer data from IoT devices equipped with sensors and actuators that continuously record vital characteristics, including energy usage, temperature, pressure, and vibration. AI algorithms (primarily machine learning or deep learning algorithms) analyze this real-time IoT data to identify anomalies, predict potential faults or failures, and optimize operational conditions [18]. Because IoT-AI systems utilize edge, fog, and cloud processing, they can make low-latency decisions for instantaneous responses, as well as conduct large-scale analytics for future improvements. IoT devices have enabled greater efficiency, improved safety, and enhanced resource utilization, resulting in reduced periods of downtime[19]. The AI-enabled adaptive control strategies within AI-IoT systems enable them to self-regulate, making industrial processes more resilient, autonomous, and in keeping with the objectives of Industry 4.0.

3.3 Applications in Cyber-physical Systems

CPS is widely applied in smart buildings, social networking and gaming, industrial networking, electric power grids and energy systems, as well as vehicular systems and transportation [20]. The important role of CPS for these industries is to have secure and safe operation systems. Below is are discussing in detail on CPS applications:

- **Green Buildings:** In the modern world, one of the biggest issues is the greenhouse effect. The ancient buildings emit greenhouse gases and consume 70% of the generated power, thereby exacerbating the greenhouse effect. The Zero Net Energy objective can be achieved by integrating control systems, cognitive management, and wireless sensor networks.
- **Smart grid:** The smart grid is an ecosystem that dependent on the collection, evaluation, and management of information. Numerous conventional components of a smart grid utilize cyber-physical systems. In addition to the client side, they are used in producing, transmission, and distribution.
- **Medical CPS:** Wireless sensor networks monitor patients' health and medication use while collecting diagnostic data. Integrating control and computational processes into the critical medical data transmitted is a fundamental prerequisite for highly dependable medical cyber-physical systems.
- **Intelligent Transportation systems:** Cyber Physical Systems offer a means of enhancing the performance of traffic system control. Control of Road Traffic Long, expansive tunnels, high-risk sub-grade slopes, urban raised bridges, bridges over rivers or the sea, and other man-made and natural environments are all examples of how cyber-physical systems create environments.

4 APPLICATIONS OF IOT–AI INTEGRATION IN SMART MANUFACTURING

The use of AI in smart manufacturing, based on the IoT, is a current research topic that enables businesses to leverage data and enhance value-added services. The installation of sensors on production equipment and the gathering of data are made possible by the development of communication technology[21]. This data may be used for a variety of AI approaches (e.g., machine learning, deep learning, reinforcement learning), such as quality prediction, collision avoidance, process selection, predictive maintenance, and repair action suggestion. IoT-powered smart manufacturing is being used by the manufacturing industry to boost industrial automation and competitiveness[22]. The introduction of smart sensors, smart machines, and wireless communication devices makes data sharing between machines, workstations, and management information systems easier. The automation of the production environment is made possible by AI, a crucial element in the growth of Industry 4.0. Various AI models and methodologies may be used to use the industrial setup's historical process data for manufacturing applications.

4.1 Predictive and Preventive Maintenance

Predictive and preventive maintenance (PdM) has transformed industrial operations by shifting from reactive repairs to proactive fault prevention. PdM leverages AI, ML, and IoT to deliver real-time monitoring and intelligent decision-making[23]. Its impact can be understood through key elements:

- **IoT-enabled sensing**: Industrial equipment is equipped with sensors and actuators that track vibration, temperature, pressure, and humidity, and provide a thorough assessment of the condition of machinery.
- **Real-time data processing**: IoT devices continuously collect and transmit operational data, forming the foundation for timely analysis and predictive insights.
- **AI and machine learning analysis**: Advanced algorithms detect abnormal patterns that indicate potential failures. The development of precise prediction models is facilitated by techniques that include SVM, neural networks, decision trees, and regression analysis.
- **Improved accuracy and efficiency**: Machine learning models optimize the forecasts with the help of historical evidence, enabling industries to minimize downtime, maximize overall efficiency, and schedule maintenance optimally.

Predictive maintenance reduces resource waste while also enhancing dependability, making it a pillar of contemporary industrial performance.

4.2 Process Optimization with AI

Predictive maintenance, one of the ways artificial intelligence is being used to streamline the manufacturing process, represents a paradigm shift in equipment management from reactive to proactive. The AI algorithms that predict equipment failure by evaluating historical and current data enable preventive maintenance interventions. This maximizes the entire manufacturing process by reducing unscheduled downtime and prolonging gear life. Quality monitoring in real-time is another area where AI excels. AI systems identify non-conformance to established quality criteria early in the production process by continuously processing production information[24]. Through this proactive approach, the number of mistakes and rework is minimized, leading to the manufacture of high-quality goods and the satisfaction of clients. AI influences inventory management and production planning through its smart solutions, which optimize resource use, modify production schedules, and forecast demand. As a result, there is less waste, resources are allocated efficiently, and companies can respond quickly to market changes.

4.3 Human-Robot Collaboration in Manufacturing Industry

In Industry 4.0, human-robot cooperation is essential. When humans and robots work together, human operators are assisted by robots in carrying out certain tasks and duties, primarily tedious tasks such as lifting heavy loads and moving large parts from one location to another [25]. To provide more precise and accurate results, the partnership aims to combine human and machine expertise. Many futuristic studies suggest that the future of manufacturing and production industries is in human-machine partnerships[26]. The primary advantages of human-robot collaboration include reduced risks, increased production flexibility, and enhanced high-quality performance, as illustrated in Figure 3, which depicts human-machine collaboration in smart factories. A methodology for human-robot collaborative production is developed by utilizing sensor technology and three gesture recognition elements, such as tracking, classification, and identification.

A collaborative robot (also known as a collaborative robot) is a robot that can learn new skills and assist people in various capacities. Additionally, the primary objective of these cobots is to collaborate with humans in the production or creation of items. Collaborative robotics, combined with AI and machine learning, produces a highly intelligent system that is crucial for the operation of industrial robots. Prominent worldwide robotics firms such as FANUC and KUKA produce collaborative robots capable of operating alongside humans; thus, the collaborative features of cobots set them apart from conventional robots.

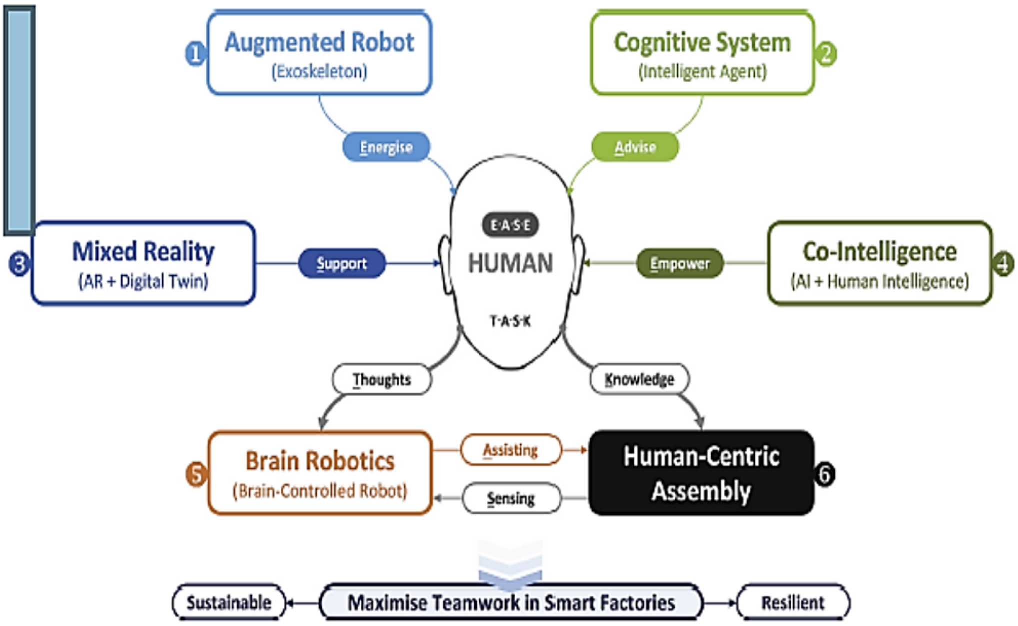

Figure 3: Human-machine collaboration in smart factories

5 LITERATURE OF REVIEW

This literature Summary highlights diverse research on IoT, AI, CPS, and Industry 4.0, emphasizing pedagogical innovations, architectural frameworks, security solutions, game-theoretic modeling, competitiveness in SMEs, and smart energy systems, while addressing challenges and proposing future industrial and academic advancements.

Kocsis *et al.* (2025), developed a pedagogical strategy that incorporates competency and personal development components with regular classroom activities in order to teach CPS as an advanced undergraduate topic. Emphasizing soft skills such as communication, cooperation, precision, time management, and attention, along with the use of ongoing accountability and reward systems, this approach mirrors the conditions and expectations of regular engineering work. The particular assignments and evaluation methods replicate real-world business and research and development scenarios, enabling students to develop into proficient engineers and researchers who may eventually hold the position of trustworthy business owners[27].

Menon *et al.* (2025) discuss the different architectures that support IoT and AIoT. Furthermore, numerous cutting-edge IoT security techniques based on ML and DL exist, including spotting irregularities or incursions, controlling access and authentication, detecting and mitigating attacks, avoiding distributed denial of service (DDoS) attacks, and examining malware in IoT. This study also examines how AIoT can be utilized to secure IoT infrastructures, optimize network efficiency, and address key challenges. Further, it discusses the innovative technologies that promise to create applications based on IoT and AIoT solutions for industries like healthcare and autonomous systems, and industrial automation, including hyperdimensional (HD) computing, blockchain, 6Genabled AIoT, and federated learning (FL)[28].

Humayun *et al.* (2024) present a classification of the difficulties in guaranteeing IoT security, discussing security concepts and strategies. Their analysis focuses on providing insights from actual case studies on privacy and ethical issues, and applies AI to IoT security. Additionally, the poll provides insight into the latest developments in IoT security in the AI era. By carefully examining IoT security as it stands now and how AI is affecting it, this survey makes important contributions to knowledge of how to create reliable and secure IoT systems[29].

Tushar *et al.* (2023) provide an in-depth insight into the numerous types of CPS and their features, followed by a clear elaboration of why game theory is applicable in the modelling of different CPS components. Finally, have a look at how game theory has been applied in earlier relevant work. This gap by offering a broad overview of various game-theoretic approaches, describing the various types of CPS and their characteristics, elucidating the reasons why game theory is suitable for modelling various CPS types, and, lastly, researching the ways in which game theory has been used to address the issues with different kinds of CPS[30].

Abdullah *et al.* (2022), Industry and academic experts' perspectives on how Industry 4.0 technologies affect MSOs' capacity to compete in the market. This has been accomplished by looking into how various I4.0 technologies impact MSOs. Experts were engaged to investigate the link between Industry 4.0 technologies and the ability to generate competitive capacities. This finding of the powerful interconnections supports the proposed I4.0 technology options, which provide businesses with a substantial competitive advantage. The result of the findings indicated that the performance of the MSOs was highly likely to be combined with the rest of the I4.0 technologies[31].

Abir *et al.* (2021), the design and performance of smart energy grid systems enabled by the IoT. To be more precise, it can focus on several IoT technologies, including computation, sensor, and communication technologies, as well as associated standards for the smart energy grid. Additionally, this site provides a comprehensive review of recent research on the application of IoT in smart grid systems. According to recent research and polls, the security vulnerability of IoT technology is one of the primary problems with IoT-enabled energy systems[32].

Table 1 summarizes present research on the integration of IoT and AI in cyber-physical systems and smart manufacturing, focusing on approaches, findings, challenges, and perspectives on the further evolution of industrial innovation and security

Table 1: Summary of a Study on IoT and AI Integration for Smart Manufacturing and Cyber-Physical Systems

Author	Study On	Approach	Key Findings	Challenges	Future Directions
Kocsis et al., (2025)	Pedagogical approach to teaching CPS	Integrated competency and personal development in classroom activities	Improved student efficiency in engineering and R&D tasks; enhanced teamwork, communication, and accountability	Balancing technical and soft skills training in CPS education	Expanding CPS-focused curricula with industry-driven simulations
Menon et al., (2025)	IoT and AIoT architectures and security	Survey of ML/DL-based anomaly detection, authentication, attack mitigation, blockchain, FL, HD computing	AIoT enhances IoT efficiency, resilience, and security; enables applications in healthcare, automation, and autonomous systems	DDoS, malware threats, scalability, and secure integration of emerging technologies	Integration of 6G-enabled AIoT, FL, blockchain, and HD computing for industrial applications
Humayun et al., (2024)	IoT protection in the age of AI	IoT security problem classification; analysis of AI-based security frameworks	Highlighted AI's role in enhancing IoT security and privacy; case studies demonstrated practical benefits	Privacy, ethics, lack of dependable security frameworks	Development of dependable, AI-driven, and ethically responsible IoT security systems
Tushar et al., (2023)	Game theory in CPS	Survey of CPS attributes and game-theoretic modeling	Game theory suitable for modeling CPS challenges and interactions	Complexity of applying game theory across diverse CPS types	Advancement of game-theoretic approaches for adaptive and scalable CPS
Abdullah et al., (2022)	Manufacturing SMEs and Industry 4.0 technologies (MSOs)	Expert survey on I4.0 adoption and competitiveness	MSO performance and competitiveness are improved with I4.0 adoption	The expense and complexity of integrating I4.0 technologies	Strategic adoption of I4.0 technologies for sustainable competitiveness
Abir et al., (2021)	Smart energy grid systems enabled by IoT	Examining IoT standards and technologies (communication, computation, and sensing)	IoT improves efficiency in smart grids but introduces vulnerabilities	Security concerns in IoT-enabled grids	Secure and resilient IoT frameworks for smart energy grids

6 CONCLUSION AND FUTURE WORK

The design of cyber-physical systems (CPS) and smart manufacturing has undergone a paradigm change with the combination of IoT and AI. This survey has highlighted the ways in which IoT enables real-time connectivity, data acquisition, and interoperability, whereas AI enables intelligent decision-making, predictive analytics, and adaptive control. Collectively, these technologies will lead to increased operational efficiency, flexibility, and sustainability. Predictive maintenance, process optimization, and fluid human-machine cooperation are all beneficial to smart factories, with CPS also applied to various areas (including healthcare, smart grids, transportation, and logistics). The combination of IoT and AI enables Industry 4.0 by providing intelligent, adaptable, and networked systems, which enable scalability, robustness, and innovation. Although these advances have been made, several challenges remain. Findings of interest include issues of interoperability across heterogeneous systems, the possibility of privacy and data security violations, as well as the ethical implications of AI-driven judgements, and the costly nature of large-scale implementation. Solving these obstacles remains critical to the widespread adoption of the same and long-term sustainability. Future research should be pursued to develop standardized frameworks and reference architectures, enabling platforms and domains to be interoperable. Cybersecurity measures and privacy-controlling AI solutions must improve to secure sensitive information. Considering these areas of research, they will enable IoT and AI to be fully integrated into CPS and smart manufacturing, ultimately leading to Industry 5.0.

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