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A Survey on AI Integration into Industry 5.0

Deepti Raj GURRAMMAGARI, Prabadevi BOOPATHY*

School of Computer Science Engineering and Information Systems, Vellore Institute of Technology, Vellore, Tamilnadu, 632006, India.

Highlights

- This paper focuses on AI and its integration into Industry 5.0.
- The emergence and evolution of Industry 5.0, Artificial Intelligence, different societal impacts.
- Different challenges and future directions addressed with AI integration into Industry 5.0.

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Abstract

Industry 5.0 (IR 5.0) is a modern production model focused on human-machine collaboration. The goal is to maintain a balance between machine and human interaction, with an emphasis on creative production and customization. Artificial intelligence (AI) will play a key role in IR 5.0 as it enables intelligent manufacturing and transforms many aspects of society. Technologies such as AI, Internet of Things (IoT), Blockchain, Virtual Reality (VR)/Augmented Reality (AR), Big Data Analytics and Cyber-Physical Systems (CPS) are essential to achieve the goals of an intelligent society. This article explores the integration of AI in IR 5.0. However, there are some challenges to overcome such as data security, ethical concerns, employee training, black box AI, etc. Despite its challenges, AI integration to IR 5.0 promises to drive automation, efficiency, and customization in manufacturing. To ensure inclusive and sustainable development, the social implications and impacts of IR 5.0 must be carefully considered.

1. INTRODUCTION

The change in implementation from manual production to automated intelligent production / manufacturing is called the Industrial Revolution (IR) [1]. This transformation has significantly changed traditional production activities, promoting growth and development. The industrial revolution not only brought about industrial changes but also profound social and intellectual changes, leading to an artificial separation between economy and urbanization, affecting class formation. Its effects resonate in politics, government, the arts, health care, and religion. The industrial revolutions that have taken place so far have brought significant changes in production, manufacturing, economy, and society [2].

Industry 5.0, also known as the Fifth Industrial Revolution, represents a new stage of industrialization. This involves humans collaborating with advanced technology and AI-enabled robots to improve workplace processes. Unlike Industry 4.0, which focused on efficiency through robots and smart machines, Industry 5.0 focuses on human impact. Key technologies include IoT (Internet of Things) and Big Data, which support human work and capabilities. Industry 5.0 emerged as a potential amendment to Industry 4.0. It emphasizes human-centricity, sustainability, and resilience in manufacturing processes. The goal is to create eco-friendly, adaptable systems that promote workforce well-being. Industry 5.0 recognizes that technology should empower humans, not replace them. It envisions a future where humans work alongside robots, leveraging technology for better results [3]. Sustainability and resilience are integral to this vision. To understand better, let's take a look at the various industrial revolutions that have taken place so far.

1.1 Motivations Behind AI Integration into Industry 5.0

*Corresponding author, e-mail: prabadevi.b@vit.ac.in

There are several motivations behind a survey on AI integration into Industry 5.0. Presenting an understanding how much AI is currently being used in different industries can help identify areas for further development. The survey can also shed light on the challenges that are preventing wider adoption of AI, such as a lack of skilled workers, concerns about data security, or the high cost of implementation. Evaluating an industry's existing infrastructure, workforce skills, and data preparedness. This survey can help to identify any gaps that need to be addressed before AI can be successfully integrated into Industry 5.0 applications. Enabling technologies that power IR 5.0 make production processes more efficient. This information can then be used to develop more targeted and effective AI solutions for Industry 5.0 [4]. The data collected from a survey can be used to inform the development of industry standards and regulations for the development and deployment of AI in Industry 5.0. This will help to ensure that AI is used in a safe, ethical, and responsible manner.

1.2. History of Industrial Revolutions

1. *First Industrial Revolution:* The first IR took place in the late 18th and early 19th century. It was characterized by the transition from manual labor and hand production methods to mechanization through the use of water and steam power. This revolution introduced new manufacturing processes, such as the spinning mills and the steam engines, which increased production efficiency and led to factory growth. IR 1.0 primarily focused on textile manufacturing and the steam engine innovations [5]. In contrast, IR 2.0 focuses on progress in steel production, automotive and power industries, enabling exponential increases in production and more advanced machinery [6].

2. Second Industrial Revolution: The second IR occurred in the late 19th and early 20th centuries and was driven by advancements in technology, especially in electricity, steel production, and the use of machinery. Industries such as steel, oil, electricity, and communications developed during this period. It also brought about mass production, assembly lines, and the expansion of transportation networks. The major drawback of IR 2.0 is the automation which led to IR 3.0 through the introduction of semiconductors and computers.

3. Third Industrial Revolution: The third IR, often called the Digital Revolution or the Information Age, emerged in the late 20th century with the advent of computers, electronics and telecommunications. This revolution has changed the way information was processed, stored, and shared. This has led to the automation of various tasks, the rise of the Internet, and the development of digital technologies that have revolutionized industries such as telecommunications, entertainment and commerce. However, although automated systems were brought into practice, all the systems still rely on human input and intervention.

4. *Fourth Industrial Revolution:* The fourth IR is the continuous industrial transformation through the integration of digital technology, AI and IoT. It is characterized by the convergence of physical, digital and biological systems. This revolution is marked by advances in areas like robotics, automation, machine learning, nanotechnology and biotechnology. It is expected to have a major impact on various fields, such as manufacturing, healthcare, transportation, and agriculture. IoT, Smart manufacturing, Industrial IoT (IIoT), and Cloud manufacturing are the four main forces behind IR 4.0. The evolution of industrial revolutions is vividly shown in Figure 1 which depicts the industrial revolution transition from Industry 1.0 to Industry 5.0.

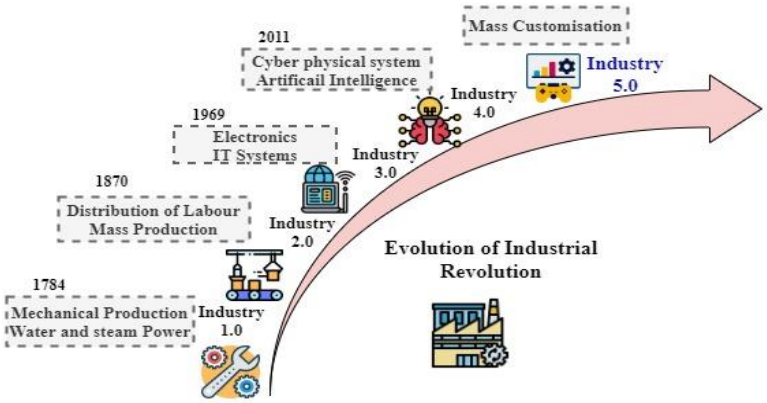

Figure 1. *The Evolution of Industrial Revolutions*

5. *Fifth Industrial Revolution:* IR 5.0 represents a recent revolution in which human-machine collaboration plays a key role in improving manufacturing processes. The transition from IR 4.0 to IR 5.0 will create higher-value professions, give designers more freedom and responsibility, and focus on personalized experiences for employees and clients [7]. Major advancements in IR 5.0 include the integration of human intelligence and cognitive computing, which will improve manufacturing speed and accuracy [8]. Additionally, environmental sustainability has become a priority with a focus on waste reduction and renewable energy systems [9]. The goal of IR 5.0 is to balance human-machine interaction to achieve remarkable benefits. In contrast to previous IRs, that emphasized on mass production and customization, IR 5.0 focuses on personalization and creative production [10]. This revolution is particularly well suited for services and applications that can benefit from a personalized and human touch and ultimately enhance the user experience.

1.3. Enabling Technologies of Industry 5.0

There are several enabling technologies that power IR 5.0. Those are AI, IoT, Big Data Analytics, Cloud Computing, Blockchain, Digital twins, Collaborative Robots (Cobots) and 6G and beyond networks. Machine learning, computer vision, and natural language processing which are part of AI are all used to create intelligent machines that can learn, adapt, and make decisions [11]. IoT is A network of physical devices embedded with sensors, software, and other technologies that collect and exchange data forms big data analytics. This data is used to monitor and optimize processes, and to develop new products and services. The ability to collect, store, analyze, and interpret vast amounts of data from a variety of sources. This data is used to improve decision-making, identify trends, and predict future outcomes. On-demand access to computing services, including storage, servers, databases, networking, analytics, intelligence, and applications.

Cloud computing allows businesses to scale their IT infrastructure up or down as needed, and to avoid the upfront costs of hardware and software. A distributed ledger technology that provides a secure, transparent, and tamper-proof way to record transactions. Blockchain can be used to track the movement of goods and materials through a supply chain, and to ensure the authenticity of products. Digital twins are the virtual representations of physical objects or systems that can be used to monitor performance, predict maintenance needs, and optimize operations [12]. Robots that are designed to work safely alongside humans. Cobots can be used to perform a variety of tasks, such as assembly, welding, and painting.The next generation of wireless communication networks that will provide faster speeds, lower latency, and greater capacity. 6G networks will be essential for supporting the real-time data processing and communication required by Industry 5.0 applications.

With the help of enabling technologies we can have increased automation and efficiency in manufacturing and other processes. They enable greater flexibility and customization in product development and production. They also provide real-time data and insights that can be used to improve decision-making and

optimize operations [13]. All the enabling technologies foster human-centered collaboration between humans and intelligent machines.

The paper is organized in the following sections. AI and its integration with IR 5.0 is discussed in section 2, the benefits and features of IR 5.0 with the use of AI are elaborated in section 3, research challenges are covered in section 4, future directions are given in section 5. The paper is concluded in section 6.

2. ARTIFICIAL INTELLIGENCE AND INDUSTRIAL REVOLUTIUON

AI is the embedding of human-like intelligence into computers so that they can think and act intelligently. AI leverages big data analytics to power various processes in its fields such as machine learning (ML), natural language processing (NLP), and deep learning (DL). ML allows computers to learn from data and make predictions. NLP allows computers to understand and process human language, while DL deals with analyzing unstructured data. AI provides powerful data analysis capabilities and has applications in diverse fields. The various branches of AI are shown in Figure 2.

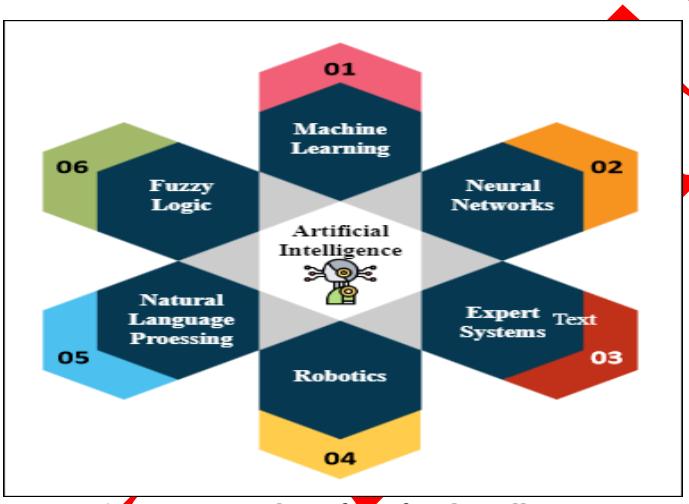

Figure 2. *Branches of Artificial Intelligence*

Machine learning is a branch of artificial intelligence (AI) that focuses on developing algorithms and models that allow computers to learn and make decisions based on data without explicit programming. The primary goal of machine learning is to enable computers to learn autonomously and make predictions or decisions based on the data provided. A neural network is a series of algorithms modeled after the human brain, designed to recognize patterns. They interpret sensory data through a kind of machine perception, labeling or grouping of raw inputs [14]. The architecture of a neural network is made up of layers of interconnected nodes, or neurons, where each connection represents a weight that is adjusted during training. An expert system is a computer program that simulates the decision-making abilities of a human expert. It is designed to solve complex problems by reasoning through blocks of knowledge, represented primarily as if-then rules rather than conventional procedural code [15].

Robotics is an interdisciplinary branch of engineering and science concerned with the design, construction, operation and use of robots. The goal of robotics is to create machines capable of assisting humans in a variety of tasks, often repetitive, dangerous, or requiring precision [16]. Natural language processing (NLP) is a field of AI) hat focuses on the interaction between computers and humans through natural language. The goal of NLP is to enable computers to understand, interpret, and produce human language in a way that is both meaningful and useful. Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory, introduced by Lotfi Zadeh in 1965. It deals with approximate reasoning rather than fixed and exact reasoning. Unlike classical binary logic, where variables must be either true or false (1 or 0), fuzzy logic variables can have true values between 0 and 1 [17].

2.1. Integration of Artificial Intelligence and Industrial Revolution

IR 5.0 is a visible revolution featuring improved connectivity through the use of mobile devices and AI. The aim is to develop a more flexible and efficient industry using digitization, customization, and the collaboration between AI and human workforce [18]. IR 5.0 focuses on faster product launches, resource efficiencies, and the simplification of tasks that impact society, education, and manufacturing. A key component of IR 5.0, IAI, applies AI to industry-specific contexts to create computerized and automated systems that increase customer value and productivity [19]. The AI revolution is having transformative impacts on financial, political, and social systems, requiring careful study of its implications for production planning, control and operational management [20, 21]. By integrating AI and human skills, IR 5.0 emphasizes personalized and customized product development, facilitating effective human-machine interaction and an interconnected technology systems [22]. A Summary of the various algorithms used, solutions and limitations for IR 5.0 applications is shown in Table 1.

Table 1. *Various Applications of AI in Industry 5.0*

Reference	**Industry 5.0 Applications**	**Purpose**	**AI algorithms used**	**Solution**	**Limitation**
[23]	Agriculture	Watering crops, To control environmental factors in the crop field.	Apriori algorithm and wireless sensor networks	Temperature for home-grown vegetables 29'C - 32'C and humidity for high productivity of lemons is 72-81% .	Not validated and suggested the process on another type of crops.
[24]	Agriculture	Disease Detection	Convolutional Neural Networks, Class weights, SMOTE, CLACHE	Accuracy is improved by 5%, whereas log loss is reduced to 0.06% from 20%.	Multiple co-occurring diseases are not analyzed.
[25]	Finance	Predicting bankruptcy of a company	Decision trees and logistic regression models are employed for early warning. Comparisons are made based on several factors.	Decision Tree gives better prediction accuracy than Logistic Regression. Therefore, DT is used for short-run prediction, and LR is used for long-run prediction.	Neural network models and genetic algorithms can also be employed.
[26]	Defence	Object Location, Underwater Mines, Cyber Security, Military Data Processing	Neural Networks, Deep Convolutional Neural Network	Rise in the performance when compared to traditional models	Real-time data set not evaluated.
[27]	Smart City	Air Pollution	Gradient Boosting Regression,	Random Forest regression performs well for pollution prediction having	Specific factors affecting the air pollution are not mentioned

			Decision Tree Regression, Random Forest Regression	different characteristics.	in detail and are not investigated.
[28]	Education in Smart cities	To attain the educational goals by better predicting the students behavior.	Random Forest Algorithm	Predicts student behavior	Real time decision making is not addressed

Industry 5.0 applications include agriculture, finance, defense, education and smart cities. In agriculture, AI algorithms such as Apriori and wireless sensor networks are used for watering crops and controlling environmental factors. In finance, decision trees and logistic regression models are employed for predicting company bankruptcy, with decision trees providing better accuracy. In defense, neural networks and deep convolutional neural networks are used for object location, underwater mines, cyber security, and military data processing. In smart cities, AI algorithms like gradient boosting regression, decision tree regression, and random forest regression are used for predicting air pollution. AI also plays a role in education in smart cities by predicting student behavior using the Random Forest algorithm.

2.2. Impact of Industry 5.0 with AI in Industrial Upcycling

The integration of AI in the IR 5.0, particularly especially in the context of industrial upcycling, can have several important implications:

1. *Enhanced efficiency:* AI technologies can simplify and automate various processes involved in industrial upcycling, increasing efficiency. Machine learning algorithms can analyze data from sensors, machines and other sources to optimize resource allocation, minimize waste and improve overall productivity.

2. *Intelligent sorting and material identification:* AI-powered vision systems and machine learning algorithms can accurately identify and sort different materials even in complex waste streams. This feature allows efficient separation of recyclable materials, facilitating the upcycling process.

3. *Quality control and defect detection:* AI can be used to detect defects and ensure the quality of up-cycled products. By analyzing visual data and using machine learning algorithms, manufacturers can identify defects and anomalies, improving the overall quality and reliability of the up cycled goods.

4. *Process optimization:* AI can optimize the upcycling process by analyzing data and identifying opportunities for improvement. By continuously monitoring and analyzing factors such as energy consumption, material usage and production parameters, AI algorithms can recommend optimizations to minimize waste, reduce energy consumption and improve overall sustainability.

5. *Supply chain optimization:* AI technologies can optimize the supply chain in industrial upcycling by analyzing demand patterns, predicting market trends and optimizing logistics. This enables manufacturers to make data-driven decisions, reduce inventory costs and ensure timely delivery of up-cycled products to customers.

6. *Advanced product design:* AI can help in the design phase of up cycled products by generating innovative ideas and providing insights based on data analysis. Using machine learning and generative design techniques, manufacturers can create new and unique products that meet customer requirements and maximize the use of resources.

In general, the integration of AI in the IR 5.0, especially in the field of industrial upcycling, can significantly improve efficiency, sustainability and product quality, leading to a circular economy and more sustainable development.

3. BENEFITS AND FEATURES OF INDUSTRY 5.0 WITH THE USE OF AI

The main benefits that AI will bring to IR 5.0 are evolution to connected environments, cognitive support, automation and cognitive biases, leadership adaptation in organizational functioning. IR 5.0 has many features with the use of AI. Figure 3 lists out all the features. The features of IR 5.0 with the use of AI are summarized below.

1. Environment Friendliness: AI technologies such as ML and DL can contribute to environmental sustainability by providing solutions to maintain a positive environmental impact [29]. In the microalgae industry, AI benefits product quality and promotes improved living standards in society [30].

2. Innovation Management: Proper alignment of the IR 5.0 enterprise model and AI information system is very important for effective implementation of innovation [31]. A robust innovation management framework and policies are required to maximize the potential benefits of IR 5.0 for business and customer needs.

3. *Design Thinking:* Design thinking combines technology and innovation policies with a company's business approach to create a sustainable environment for IoT and IR 5.0. By focusing on customer value and balancing reliability and effectiveness, design thinking enables companies to develop extraordinary ideas and seize opportunities [32].

4. *Risk Detection:* AI-supported application of actionable system models helps monitor and detect risks and adapts to corporate strategy. ML algorithms and automated systems with AI and machine learning capabilities can help reduce risks in processing and facilitate risk detection [33].

5. *Intelligent Systems:* AI techniques enables machines to learn and execute tasks autonomously. DL strategies such as classification, regression, and clustering methodologies provide solutions for intelligent systems. Intelligent autonomous systems, also known as "COBOTS," combine sensor technology and predictive behavior, paying attention to safety standards and work-related risks [34].

6. *Intelligent Devices:* Powered by purpose-built AI chipsets, on-device AI brings computing to the edge to manage privacy risks, reduce latency, and minimize network dependency. Smart devices augment customer knowledge and automatically deliver personalized services and experiences. In the medical industry, AI is monitoring various aspects such as blood sugar levels and insulin administration. In manufacturing, intelligent factories automate processes with the support of industrial robots.

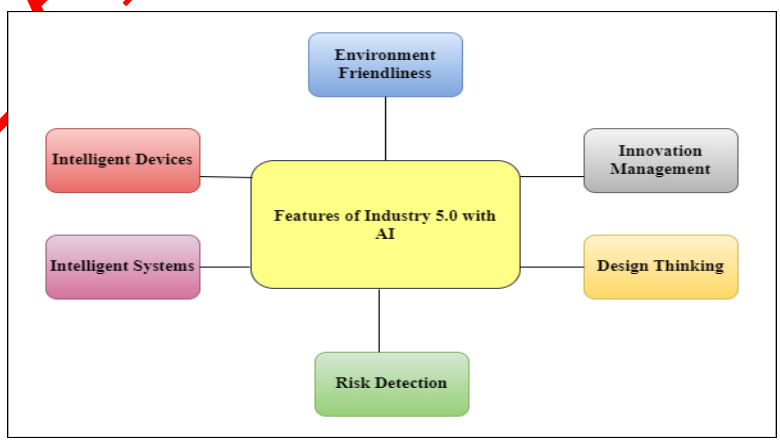

Figure 3. *Features of Industry 5.0 with AI*

3.1. Societal Impact of Industry 5.0

IR 5.0 explores the concept of humans and work robots complementing each other's inherent strengths rather than outright replacing human workers [35]. IR 5.0 includes technological advancements and the integration of humans into the industrial environment. This shift has had a profound impact on various societal domains, as illustrated in Table 2. With the advent of IR 5.0 development, the industry's daily activities in industries have changed to leverage the benefits of both technology and human integration. This evolution in industrial practice has enabled a more balanced approach that combines human creativity, skill, and adaptability with the efficiency and precision of robotic systems [36]. Embracing the development of IR 5.0 will have a significant impact on various sectors of society.

Table 2. *Societal areas which have an impact of incorporating IR 5.0 developments*

S.No	Societal Area	Impact
1.	Agriculture 5.0	• Agriculture robot • Monitor crop, soil, and water, Weather forecasting • Precision farming and predictive analysis
2.	Defence 5.0	• Cyber Security, Battlefield healthcare • Logistics and Transportation • AI and Data information processing
3.	Finance 5.0	• Portfolio management • Algorithm trading and Fraud Detection • Sentiment analysis and Customer service
4.	Law 5.0	• Legal Analytics, Document automation / expertise • Electronic Billing, Due Diligence
5.	Smart city 5.0	• Smart Traffic management • Street Lighting and Public safety management • Water management systems, Intelligent parking systems
6.	Transportation 5.0	• Driving perspective analysis, ensuring highly secure routes • Traffic control and analysis, public transportation management • Intelligent transportation systems, Smart city logistics

1. Agriculture 5.0: Agriculture 5.0 intends to revolutionize the agriculture sector for a more resilient and technologically sophisticated future by addressing global issues including food security, climate change and sustainability. This stage of agriculture uses connected AI and robotics to increase production while ensuring environmental sustainability [37]. This includes autonomous systems, data-driven agriculture, and precision farming techniques to optimize efficiency and transform how goods are brought into market. The various aspects of agriculture 5.0 are illustrated in Figure 4.

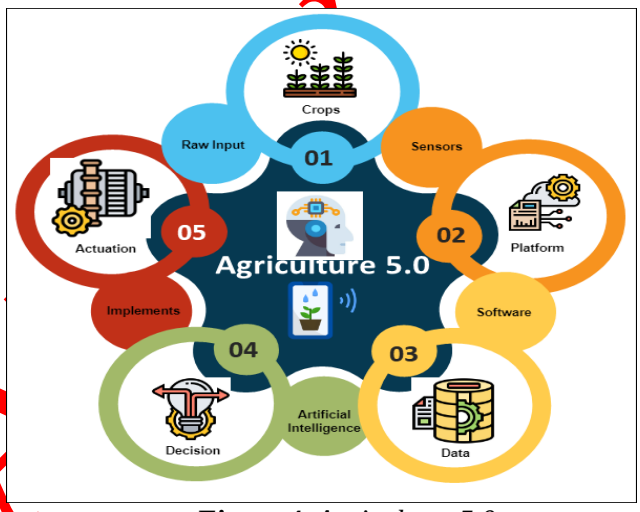

Figure 4. *Agriculture 5.0*

2. Defence 5.0: The term "Defence 5.0" describes how AI, self-governing systems, and cyber capabilities are incorporated into contemporary defence plans to provide more effective and efficient decision-making and operations. Future warfare is expected to be guided by unmanned systems, including bio-inspired robots [38]. AI plays an important role in military applications, providing alternatives for planning, information exploration, data analysis, training, simulation, attack, defense, war-games, and command information [39].

3. *Finance 5.0:* Finance 5.0 describes how blockchain, AI, and other cutting-edge technologies are being incorporated into the financial services industry. AI is revolutionizing the financial sector by streamlining processes, improving customer experience, identifying fraudulent transactions, and providing financial recommendations. It is also useful for predicting the financial situation of companies and supports the decision-making of financial institutions [40].

4. *Law 5.0:* Law 5.0 might boost the general justice experience for people and organizations while also increasing the effectiveness, accuracy, and accessibility of legal services. It also brings up significant issues about the function of human lawyers, moral issues, and the requirement for legal frameworks to guarantee that technology advancements advance the public interest. The legal field is gradually adopting digital advancements to build relationships between citizens, businesses, and institutions. The use of AI in the legal field is evolving, but still in transition to the IR 5.0 era.

5. Smart City 5.0: Smart City 5.0 is the term used to describe how urban planning, administration, and governance are using cutting edge technology like AI, IoT, blockchain, and quantum computing. The goal of smart city 5.0 is to build livable, resilient, and sustainable urban environments by utilizing technology to solve difficult urban problems and enhance the standard of living for citizens. It requires a comprehensive approach that incorporates social responsibility, innovation, and togetherness. Smart cities play an important role in building sustainable and safe environment. These include various concepts such as smart traffic management, street lighting, public safety, water management, parking systems, waste management, governance, and planning management to improve people's welfare [41].

6. *Transportation 5.0:* Transportation systems are evolving through integration of advanced computing, network technologies, and real-time social and physical systems. Transportation 5.0, also known as the Intelligent Transportation Systems, uses Cyber-Physical-Social-Systems (CPSS) for future analytics, secure routes, traffic control and research, public transport management and allows optimization for smart city logistics. With the help of transportation 5.0, travel will reportedly become more economical, accessible, connected, safe, efficient, and ecologically friendly. This revolution will bring about smooth multimodal travel, less traffic, and an improved standard of living. It will also transform urban planning, logistics, and the transportation sector as a whole.

Overall, the inclusion of IR 5.0 developments will impact agriculture, defence, finance, law, smart cities, and transportation systems bringing significant progress, efficiency gains and changes in their respective areas.

4. RESEARCH CHALLENGES

This section focuses on research challenges in integrating AI and IR 5.0. These research challenges address data integration, workforce skills, computational requirements, legal compliance, transparency, ethics, data quality, privacy and security concerns to advance the field of AI integration to IR 5.0 and enable its responsible and beneficial applications.

1. *Data Assimilation and Data Issues in AI Models:* Integrating large amounts of data from various sources into AI systems poses the challenge of data integration in the IR 5.0 domain. Data assimilation combines observational data with underlying dynamic principles to estimate quantities of interest [42, 43]. The quality of collected data has a significant impact on the performance of AI and ML models, making data collection and maintenance difficult.

2. Skilled Workforce Needs of AI Systems: The introduction of new digital technologies, including AI, requires a skilled workforce [44]. New companies can hire employees with specific skills, but existing companies face the challenge of upskilling their workforce to address AI challenges in the IR 5.0 world. Analytical thinking, innovation, active learning, creativity, and critical thinking analysis are among the AI talents needed for skilled workers, resulting in a shortage of technical knowledge and expensive labor.

3.Inability to Afford Computational Requirements of AI: AI, ML, and DL models require a large amount of computational power, such as high-end processors and GPUs. This need for computing resources, combined with the need for large amounts of data, can be prohibitively expensive for many organizations. Access to IR 5.0's powerful infrastructure solutions is critical to meet the growing complexity and computational demands of AI systems.

4. Insufficient Legal and Regulatory Compliance: The use of AI involves large amounts of data, raising concerns about data leakage and privacy. Erroneous algorithms in IR 5.0 applications can lead to legal issues. Data privacy and proper handling of personal data are essential and require proper data processing by companies. Legal regulations, such as the General Data Protection Regulation (GDPR), aims to protect data and ensure accountability, but there remains a comprehensive data use and privacy legislation [45].

5. Issues with Blackbox AI: Many AI models act as black boxes with opaque internal and decision-making processes [46]. The lack of explainability raises concerns about the credibility and reliability of AI algorithms to be used in IR 5.0. Understanding the inner workings of AI systems is critical to gaining public trust and acceptance.

6. Issues in Developing Explainable, Ethical, and Acceptable AI Applications: Ethical considerations must be considered when developing and using AI in IR 5.0 applications. Ethical concerns include job displacement, lack of trust, security issues, transparency, bias and discrimination, misuse of personal data, environmental impact, and impact on democracy and judiciary systems. To use AI responsibly in IR 5.0, it is important to address these concerns and ensure the ethical use of AI.

7. Data Quality, Privacy, and Security in AI: working with high-dimensional data requires consideration of data quality and compliance with data protection and security measures. Poor software implementations or changes in data formats can affect data quality [27]. Data validation and accurate data storage are important to ensure accuracy and effective data management. Exploitation of data in unethical AI systems without proper authorization raises concerns about privacy invasion and societal repercussions, highlighting the need for effective action and understanding of law [47].

5. FUTURE DIRECTIONS

This section presents some of the future direction concepts for IR 5.0. To gain more support for the use of AI algorithms and technologies for additional benefits in the era of IR 5.0, these should be seriously considered. The future directions of Industry 5.0 that can benefit from AI algorithms and technologies are:

1.Explainable AI (XAI) for IR 5.0: Focus on developing AI models with explainable capabilities to improve transparency and understandability. XAI helps researchers analyze and understand the root causes of AI results and remove the limitations of black-box AI systems [28].

2.Quantum Computing for IR 5.0: With its high computing power, quantum computing will greatly improve data processing and enable faster use of information in AI. The integration of AI and quantum promises to solve complex problems, optimize datasets, and increase computational speed [48].

3.Blockchain AI for IR 5.0: Blockchain technology and cryptography will play an important role in building real-time applications in IR 5.0. Permissioned blockchains facilitate secure and transparent data exchange, enabling hyper-personalization and massive customization. Blockchain also ensures data protection, secure exchange of information and resources, and compensation for data owners [49].

4.Sixth Generation Wireless Communication Networks for Industry 5.0: The development of 6G wireless communication networks aims to build a fully connected and intelligent digital world [50]. 6G networks will provide the infrastructure for advanced AI applications and services with faster data speeds, increased capacity, lower latency, and improved security and quality of service [51].

5.Metaverse: The metaverse represents a shared online environment that integrates the real and virtual worlds [52]. By combining AI with technologies like AR/VR, blockchain, and networking, the Metaverse can create scalable and realistic virtual worlds. care must be taken to ensure security and privacy protections in this digital space.

These future directions highlights the importance of explainability, quantum computing, blockchain integration, advanced wireless networks, and the emergence of the Metaverse in driving IR 5.0 and harnessing the potential of AI technologies. Furthermore, the future IR wave IR 6.0, featuring the dominance of AI in anticipating human needs and planning resources, concerns the implementation of AI with robotics, with a focus on 3D printing and computer-aided manufacturing for industrial tools and mechanical modeling [53, 54]. The development of innovative technologies and applications for IR 4.0 and IR 5.0 should support the realization of the futuristic IR 6.0.

6. CONCLUSION

The evolution of industrial revolutions has brought us to the brink of a new era: IR 5.0. This latest revolution aims to combine human intelligence with cognitive computing capabilities, as well as robots and intelligent machines, to revolutionize production methods and efficiency in smart manufacturing environments. By integrating AI into industrial processes, IR 5.0 seeks to improve manufacturing processes, ensuring the timely delivery of flawless goods. This article provides an overview of previous industrial revolutions, from IR 1.0, characterized by mechanization using water and steam power, t0 IR 2.0 with mass production and electricity, to IR 3.0 with computers and automation, to the IR 4.0 with cyber-physical systems and IoT, emphasizing the accelerating pace of technological advancements. Each phase has gradually transformed the production landscape, improved productivity and modified social structures. IR 5.0 represents a significant leap forward, emphasizing the combination of advanced AI with human creativity and decision-making capabilities. This symbiosis is poised to drive the next wave of efficiency in manufacturing, characterized by intelligent decision-making, predictive maintenance, and adaptive learning systems. By leveraging AI, manufacturers can anticipate problems before they arise, optimize resource usage, and achieve unprecedented levels of accuracy and speed. As AI and robots take on more complex tasks, the nature of work will evolve, requiring new skills and potentially leading to changes in employment patterns. Understanding these societal impacts is critical for researchers and practitioners who want to guide the technological vision that shapes our future. This article also highlights future prospects of IR 5.0, focusing on the integration of upcoming technologies such as XAI, blockchain, and 6G wireless connectivity. XAI promises transparency in AI decision-making, enhancing trust and accountability. Blockchain can ensure a secure and transparent supply chain, while 6G wireless connectivity will provide the bandwidth and speed needed for real-time data processing and communication. These advancements are expected to make manufacturing processes not only safer and faster but also more flexible and adaptable. This article also acknowledges that there are technical implementation challenges that still need to be considered in more depth, especially in the context of human-robot collaboration.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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