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REVIEW ARTICLE

Blockchain enabled artificial intelligence for Industry 5.0: Vision, challenges and opportunities

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ABSTRACT

Internet of Things (IoT) devices are important in the modern day as traditional equipment grow more autonomous and intelligent. On the one hand, high-speed data transmission is a major problem, where the 5G environment plays a important role. Nevertheless, many IoT devices use protocols that are built on centralized design to transfer data, which may result in a number of security risks for the data. A number of difficulties, including autonomous robotics, self-driving cars, virtual reality, and security issues, are resolved by integrating artificial intelligence with 5G wireless technologies. Hypercognitive approaches, the integration of virtualized and extended worlds, twin and prototypes structures for digital equipment, dependable machine boundaries, collaborative robots, and supply chains powered by artificial intelligence are all credited with the transition (AI). Industry 5.0, a new trend, is anticipated to go beyond the reach of Industry 4.0 ecosystems and make use of large production with user-centered customizations. The sharing of data, however, occurs across several heterogeneous networks that span various authoritative domains. In order to coordinate and safeguard the industrial perimeters, dependable and secured information transfer is important. This research work covers a wide range of tactics, including the IoTs, collaborating robotics, blockchain, digital twins, big data analytics, and upcoming 6G networks. In order to comprehend the issues brought on by interactions between the humans and the robots in the assembly line, the research also took into account the difficulties and issues that were examined in this research.

Keywords: Blockchain (BC); artificial intelligence; Internet of Things; Industry 5.0; security; privacy; scalability

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1. Introduction

There are many industrial revolutions exist in this current smart era, in which the popular one is industrial revolution 4.0. The fourth industrial revolution, also referred to as Industry 4.0, is now taking place. It incorporated critical systems contains the Internet of Things (IoT), artificial intelligence (AI), cloud computing (CC), and edge computing with industrial applications that were automated in order to spread the concept of smart manufacturers and enhance output. The previous iterations, when the only goals were productivity improvement and mass production, have been transformed by Industry 4.0. Industry 1.0, which began in the 1970s, is mechanical, with the production of steam and water serving as the main driving forces. Henry Ford, who combined the concepts of assembly lines and electrical production into accessible, mass-produced machinery in 1870, is credited with developing industry 2.0 assembly line manufacture. With the third industrial revolution, digitization replaced mechanical operations, and some industrial activities started to be partially automated. This generation's industrial projects use large-sized computers and memory-programmable controllers' logic, which minimizes the need for human labor. Industry 4.0 underwent a major across the world in 2011. This guiding future activities network to give support production lines, which are assisted by technology for information and communication. Moreover, Industry 4.0 witnessed the creation of IoT-driven cyber-physical systems (CPS), which promoted the idea of the "smart factory" and allowed autonomous monitoring, self-organized manufacturing, and networked logistics to boost business profits[1]. Industry 5.0, which stresses expanded involvement in human-machine interactions, presents the cognitive control concept from Industry 4.0 (refer **Figures 1** and **2**).

By integrating human experience with AI, Industry 5.0 can build precise control and cognitive capabilities. The vision for Industry 5.0 has been established by expertise based on control, intelligent behavior, and manufactured principles. The goal of Industry 5.0 is to enable robots to execute laborious and repetitive activities, freeing up human labour for jobs which require intelligence and critical thought. This will improve the quality of output. By automating tedious and repetitive processes, Industry 5.0 aims to increase the quality of production while freeing up labor to focus on critical thinking and intelligent jobs. It would produce a niche market for skilled people. In the mass customization-focused Industry 5.0, humans will operate robots. CPS is closely related to Industry 5.0, which involves humans and robots interacting collaboratively. The fundamental building blocks of process management would be collaborative robots, or cobots. Also, it would be greener because the emphasis would be on sustainability development and manufacturing[2,3].

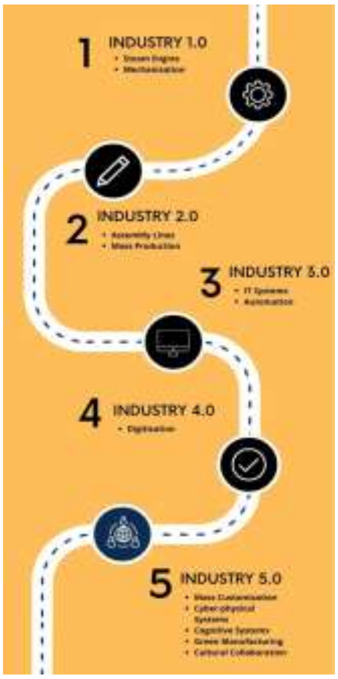

Figure 1. Evolution of Industry 5.0.

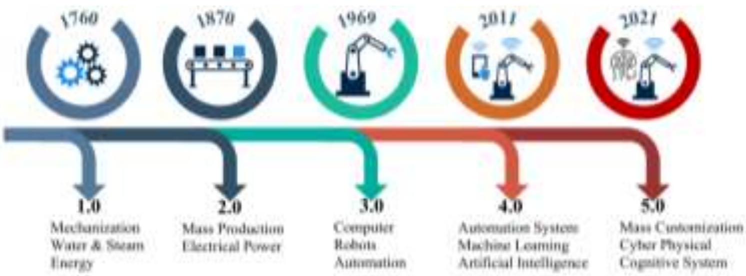

Figure 2. A prospective shift towards Industry 5.0 ecosystem.

Automation is imperative, and pipelines powered by AI would benefit from efficient machine learning (ML), deep learning (DL), and reinforcement learning (RL) algorithms. Yet, the human element must be included in order to control the activities effectively. Huge amounts of data would be exchanged online via authorized wireless networking pathways during the operations of Industry 5.0, which is driven by CPS. As malicious attacks have the ability to compromise the security and privacy of sensitive information, it is necessary to protect information about the process from them. Also, the client data must be safeguarded among interacting nodes employing certain standards. The initial stages in addressing privacy issues are user-defined data access parameters and fair information procedures[4].

When privacy-preserving strategies are utilized because obvious information fields would be obscured, AI models wouldn't be capable of efficiently customise themselves so that less information needed to be provided. The need for privacy trade-offs and personalization must therefore be balanced. But because they do not take into consideration the unique behavior of sensor nodes, privacy- and security-based solutions fall short. Trust in data flows and control are important when several, independent networks participate in Industry 5.0. A system called blockchain (BC) may make it possible to create open ledgers where industrial process information can easily track and maintained. In a peer-to-peer (P2P) network, documenting transactions and tracking assets is made easier by the shared, distributed, and immutable ledger known as BC. It creates reliable reviewing platforms that support auditing and compliance objectives. It creates dependable reviewing platforms that support auditing and compliance objectives[5]. BC compiles entries regularly and in reverse chronological order, essentially acting as a digital data ledger. In BC, the hash for the block that came before it is connected to the hash for the block header. Data cannot be modified once it has been added to the chain. The block's hash is altered whenever one or more of the transactions are updated.

In Industry 5.0 supply chains, smart contracts (SCs) are important for automating service-oriented behavior, access management, and privacy enforcement. To handle assets, goods, items, and services, SC-assisted digital IDs are utilized[6]. The contract low level interface allows SCs to communicate with the underlying Blockchain network and facilitates consumer agreements. An evolution of Industry has been discussed in **Figure 1**.

2. Literature review

Garcia et al.[7] gives several examples of how AI and IoT are used together, demonstrating how this combination might lead to some extremely useful and intriguing applications. The article briefly discusses the four most important components of AI: Machine learning, computer vision, fuzzy logic, and natural language processing. IoT is also seeking to harness these subfields to create smarter machines or algorithms to help us in our day-to-day activities. Fuzzy Logic, for example, might be utilized to provide intelligence and make choices that conserve resources such as money and electricity; and other resources; Computer Vision could automate visual situations; NLP may be employed to enhance the understanding between machines and humans; and Machine Learning could give intelligence and make choices.

Guiza et al.[8] give a high-level overview of the IoT with a focus on supporting methods, protocols, and application issues. Modern RFID, smart sensor, communication, and Internet protocol advancements are what make the IoT possible. The main goal is to develop new classes of applications without the aid of humans by allowing smart sensors to work together directly. It is possible to think of the current Internet, mobile, and machine-to-machine (M2M) technology boom as the initial stage of the IoTs. IoT is anticipated to connect physical items in the years to come in order to facilitate intelligent decision-making, combining various technologies to allow new applications. An overview of the IoT is given in the beginning of this article. In the section that follows, we give a broad overview of certain technical details relating to the IoT enabling technologies, protocols, and applications.

Lin et al.[9] fog/edge computing has been suggested to be linked with IoT in order to enable computing services devices installed at network edges and improve user experience and services resilience in the event of failures. Fog/edge computing's dispersed design and close proximity to end users can provide improved service quality and faster response times for IoT systems. As a result, the infrastructure for IoT advancement in the future will be based on fog/edge computing. It is important to first assess the architecture, enablers, and issues related to IoT before developing an IoT infrastructure based on fog/edge computing. The integration of fog/edge computing with IoT could then only be thought about after that. This paper gives a comprehensive overview of IoT, covering system design, enabling technologies, security and privacy issues, the integration of fog/edge computing and IoT, as well as applications. In the first part of the study, the relationship between IoT and Cyber-Physical Systems (CPS), both of which are essential to the creation of an intelligent cyber-physical world, is focused on examining.

Further, Samie et al.[10] examines how machine learning works in the IoTs, including embedded hardware and the cloud. Investigated are a number of machine learning applications for data processing and management tasks. The cutting-edge machine learning applications in the IoT are classified according to the application domain, input data type, machine learning techniques used, and their location along the cloud to thing continuum. The challenges and current areas of research for efficient machine learning at the IoT edge are discussed[11]. Moreover, machine learning classification techniques are used to get and analyze papers on "machine learning in IoT" systematically. The expanding fields of study and application are then determined.

The AI-based technologies that make up the IoTs are a important part of the Industry 5.0 paradigm[12]. With precise production automation and the use of critical thinking abilities, Industry 5.0 demonstrated a substantial relationship between intelligent systems and humans in the majority of applications. Also, industry 5.0 introduces a number of capable tools that support organizations' ability to work on a budget and make quick changes without having to make any initial investments. IoT ecosystems have greatly improved in recent years thanks to rapid advancements in smart devices, wireless connectivity, and sensor nodes. Note that IoT is a network of interconnected, web-connected objects that can wirelessly acquire and transmit data without requiring human interaction.

The majority of fields have undergone digitalization in the twenty-first century. We must acknowledge, though, that businesses find it challenging to implement industry 4.0, IoT, and AI technology in their operations. Aside from the aforementioned technologies, industry 5.0, the next phase of the Industrial Revolution, will appear in the following years[13]. The phrase "industry 5.0" became popular in the beginning of 2015; however, it was actually referred to as the "fifth industrial revolution," which had a major impact on a variety of fields, particularly day-to-day business, due to the speed at which new technologies were being added and improved and the shifting integration of human processes[14].

The first Industrial Revolution, commonly defined as Industry 1.0, which began at the end of the 18th century involved the industrialization of mechanical parts using the power of people, animals, water, and streams. The final quarter of the 19th century saw the start of the second industrial revolution, sometimes known as Industry 2.0. One of its distinguishing features was the mass manufacture of goods using electrical energy[15]. Mechanization, mass production, assembly line developments, the telephone, and the telegraph are only a few traits of Industry 2.0. The third industrial revolution, commonly called "Industry 3.0," began in the first half of the 20th century. Computerization and microelectronics were utilized in the industrialized region. Most of these initiatives from the 20th century, which are closely associated with information and communications technologies, incorporate increasing levels of automated processes made feasible by robots, computerization, and microprocessors[16]. The third revolution is being used in a number of industries, including flexible production methods, computer-integrated production, and computer-aided process planning. Industry 4.0, often defined as the fourth industrial revolution, began with the introduction of Cyber Physical Systems (CPS), which rapidly changed the manufacturing sector. IoT, augmented reality, cloud computing, big data analytics, simulations, and sophisticated devices were the main elements of Industry 4.0[17]. It can be seen from the pursuit of fully integrated platforms that end-to-end digitization and the integration of digital industrial ecosystems are given top importance[18]. Also, it gave a lot of attention to IoT gadgets connected to the industrial plant.

Industry 5.0 places a heavy emphasis on collaboration across different kinds of technology, implying that the fifth industrial revolution is growing increasingly fascinated by cutting-edge human-machine interfaces through human-machine interaction. To push Industry 4.0 to a higher level is the primary goal of Industry 5.0. The idea of collaborative robots, or cobots, is introduced for this. With a successful integration, cobots will meet the demand for businesses that offer individualized products today. As a result, Industry 5.0 is more well-known in manufacturing and medical than other related fields thanks to advancements in robotics, software tools, the internet of everything, and manufactured (refer **Table 1**).

It gives customers the possibility to experience mass customisation in the global collaboration of many groups. Technological advancements must prioritize client objectives because they are the core of every organizational change. Industry 5.0 adheres to the following concepts to achieve client goals: Enhance accurate pricing and the degree of client contentment with different product or service customization. Customer-centric computing lays an emphasis on customer goals and tries to reengineer impediments to corporate expansion whereas green computing emphasizes environmental considerations. Cyber-Physical Systems (CPSs) create an intelligent framework from the human servicing the customers by fusing artificial intelligence with human strengths.

Table 1. Evolution of Industry 1.0 to Industry 5.0.

Phase	Period	Description	Identification by	Key point
Industry 1.0	1780	Stream and water devices are used in industrial production.	Mechanization Water and stream	First mechanical Loom
Industry 2.0	1870	electric powered mass manufacturing	Electrification Division of labor Mass production	First assembly line
Industry 3.0	1970	using electronic and IT systems to automate	Automation Electronics IT systems	The first programmable logic controller
Industry 4.0	2011	Automating industry output with connected devices, data analytics, and computerized machinery	Globalization Digitalization IoT, Robotics, Big data, Cloud computing	Cyber-physical systems
Industry 5.0	Future	combining human and machine intelligence to enhance goods and services	Personalization Robotics and AI Sustainability	Human-robot coworking Bio-economy

3. Reasons for adopting Industry 5.0 in manufacturing

Industry 5.0 will provide guidance or provide a solution for the problems faced by eliminating human workers from various manufacturing operations as discussed above. To support the industry 5.0 producer, however, there is a requirement for cutting-edge technology. Advances in digital twin technology combined with sophisticated autonomous systems have made evaluation monitoring of manufacturing locations more challenging. Top Industry 5.0 enablers include additive manufacturing, multi-agent technologies, smart manufacturing, the digital eco-system, collaborative robotics, the internet of everything, mixed reality, industrial blockchain, drones, 5G, and beyond. Visualization tools are important in creating the rules for controlling and customizing real products before product outlines. Smart homes, autonomous manufacturing cobots, and distributed intelligent framework have all dramatically increased the interoperability of small sensor data and sensor node utilization. It seems inevitable that the sensing and gathering of raw real-world data by these intelligent sensor nodes will contribute to the next industrial revolution. Energy optimization, rapid and effective customisation, choosing a local agent for information pre-processing, and producing highly modelled distributed intelligence in IoT, Industrial 4.0, are still unresolved research issues.

As big data and AI-based cobots continue to advance, using a digital twin in virtual reality is becoming more and more practical. It helps industry experts to develop systems and process flows that allow for minimal waste. Due to the digital twin's improved visualization features, the throughput of every part will consequently be rapidly increased. With the help of real-time trackers, consumers' sales orders can be combined with manufacturing orders and auxiliary supplies. When a teacher or learner is in another location but is receiving virtual training to perform a certain task in a simulated or virtual environment, it will be helpful. For both parties, the cost and duration of this training are drastically reduced. The manufacturing industry has a lot to benefit from autonomously controlling production lines thanks to artificial intelligence frameworks and clever automation technologies. Contemporary AI-related ML and DL models successfully restructure organizations and smart solutions that aid in decision-making. Transfer learning transfer learning techniques in Industry 5.0 secure and advance the aforementioned programs. Primitive vision and other sensory capacities have showed huge promise for replication by computer vision using DL, RL, and GPU-based computation. Yet, cobots' proficiencies need to be increased subtly if industry 5.0 is to perform at its highest level.

4. Our motivation behind this work

Consensus mechanisms control the scalability, node throughput, and mining latency of the BC networks and play a vital role in their proper management. For responsive information sharing in industry applications, the resource-intensive PoW and PoS consensus approaches are inadequate. A permissioned BC is the best methodology for organizing and maintaining real-time data in Industry 5.0 contexts, where low-powered consensus mechanisms like RAFT, Tangle, IOTA, and Omniledger are frequently utilized[19]. Another essential part of BC's fourth generation is developing validated models to prevent attacks like Sybil, distributing denial-of-service (DDoS), and 51% attacks. One of the many attacks sets that SC is vulnerable to includes code injection, reentrancy, out-of-order, and gas attacks, all of which should be avoided by a safe BC design. The proposed consensus is assured to be acceptable and scalable as part of Industry 5.0 by a number of business-related techniques and hash graph techniques.

With the aid of precise and accurate control and modeling technologies, Industry 5.0 is expected to include human input into the automated systems. When information is exchanged across public wireless networks, security becomes a top priority to protect industrial systems. As a result, BC is a key Using auditable, dated, and timestamped ledgers, Industry 5.0 offers a method for utilizing trusted control. The vision, key technologies, and process-driven actions are covered in preliminary research on Industry 5.0. But, Industry 5.0 must take security seriously. We think this is the first piece to discuss the importance of BC as an Industry 5.0 enabler. The goal of the article is unimportant. In this article, we go over the key technical elements of Industry 5.0 that BC is supporting across a number of Industry 5.0 verticals, such as smart manufacturing, sensor-driven controls, healthcare, robotics, and value-driven commercial applications. The research study in the essay carefully exemplifies the BC-leveraged Industries 5.0 concept in the pertinent industries, as well as the architectural challenges, security issues, and use case examples.

5. Artificial intelligence for Industry 5.0

Recent improvements to Industry 4.0 have been referred to as "future customisation services in industry." The fifth industrial revolution, or "Industry 5.0," emphasizes intelligent interaction between humans and machines and makes use of cognitive-based services and artificial intelligence. IoT, blockchain, virtual reality, fuzzy inference frameworks, deep learning-based neural networks (DNNs), convolutional neural networks, stacked autoencoders, deep reinforcement learning, meta-learning, life-long learning, and graph neural networks, as well as meta-heuristic algorithms, have all played an essential role in improving manufacturing quality, that also manages to combine people, methods, and machines[20]. In additional to Industry 4.0, Industry 5.0 refers to technical advancements made to the services offered, especially when it comes to impending personalization services. In the middle of all of this, these developing Ai systems also offer strong bases for the connectivity of infrastructure, data, energy, transportation, and government, which is fueling several innovations for various industrial reasons.

In order to advance Industry 5.0, supply chain management, manufacturing quality, and smart cities, there is a need to further study the many uses of these AI technologies. The objective of the special issue is to provide a place for discussions on novel scientific and technological findings, algorithms, and experiences in these types of articles, including but not limited to those listed below;

- Considerable reductions in unscheduled downtime due to better-designed goods;
- novel AI-based data analytics to increase productivity, product quality, and worker safety;
- Data-driven improvements for logistics management and demand planning;
- supply chains that are green and based on AI;
- IoT applications for monitoring manufacturing across all supply chain operations;
- Improvements to industry with AI technology 5.0 and the interconnectedness of all smart city elements;
- The use of hybrid AI and meta-heuristic algorithms to improve Industry 5.0 and the interconnectedness of all elements in smart cities;
- Intelligent approaches for upcoming smart industries;
- IoT in industry 5.0;
- Industry 5.0’s use of cloud and data analytics to efficiently analyze industrial data;
- Innovative or enhanced optimization algorithms with a focus on nature to enhance Industry 5.0 and the interconnectedness of all elements for smart cities.

By placing the worker at the heart of the manufacturing method and utilizing new technology, Industry 5.0 respects the planet’s production limits while delivering prosperity that goes beyond jobs and growth. It enhances the current “Industry 4.0” strategy by placing research and innovation at the service of the shift to a sustainability, human-centered, and resilient industry. AI has offered products that make use of data from intelligent sensors, equipment, and gadgets, enabling the creation of actionable insight and assisting in the improvement of production efficiency. But there hasn’t been a parallel emphasis on or advancement in core human-centered systems and procedures to go along with this AI evolution. The capacities in industry and the decision-making processes are improved by several practical aspects of artificial intelligence[21]. The supports for enhancing the services for Industry 5.0 is growing rapidly due to AI-enabled technologies. The development of cognitive tools and analytics in several innovations and real-time applications across the sector is largely influenced by the practical features of artificial intelligence in the interim. As an illustration, consider stock forecasting, prescriptive analytics, e-health and medical communication, IoT, intelligent solutions, etc. As a result, the special issue offers a forum for the gathering of pertinent and original studies as well as review articles for debate of scientific and technological topics. For upcoming researchers and users in the modern era, the special issue aims to deliver a high-quality journal with unique ideas and application methods.

6. Blockchain for Industry 5.0

This part describes a sample structure for Industry 5.0 with Blockchain based. Based on the standard design, we offer the Blockchain-based Industry 5.0 supported solution taxonomy. Hence, the section responds to the given RQ2 and RQ3. This article will discuss a thorough reference framework for Industry 5.0 that is Blockchain-enabled and utilized to guarantee secure connection across several procedures. The suggested solution taxonomy addresses RQ3, in addition to all pertinent use-cases of BC in Industry 5.0.

The BC networks create a unique hash using cryptographic hash algorithms like MD-5, SHA-256, or SHA-512 in order to verify a transaction. The nonce values and transaction list are hashed, and the hash of the block before this one is used to create the hash for this one. Hence, BC creates a solid network of transactions. Any new transactions must be approved and confirmed by all network nodes or SCs before being added. The new, immutable block that is being introduced stretches the existing BC. A decentralized, trustworthy system is produced by this immutable ledger. User status and transaction information are verified using consensus procedures.

The gathered information from many industries is kept in the BC using transactional ledgers. A permissioned BC is the recommended choice for storing transaction-based documents in industrial settings. Because it keeps the information independent of the quirks of the operating system and functions as a decentralized computer, a virtual machine (VM) is the best option for executing transactions on Blockchain. The primary BC is connected to many chains that are unique to each application in order to scale the transactions[22]. Requests sent using the API can reference to the BC nodes. Many consensus methods, which are reliant on the underlying applications and the network architecture, provide high transactional throughput. Whenever a healthcare service saves patient medical records locally, a global modeling is downloaded and trained on the local storage. The federated learning paradigm protects data integrity and privacy by not sharing data locally. In order to assess the complete cold-chain process for the COVID-19 immunization, we can automate service level agreements between consumers/ users and build up user identity and purchase information via smart contracts.

7. Popular issues raised in blockchain enable AI for Industry 5.0

Technology acceptance and technological trust are essential. People who use the new technologies are being trained at the same time as technology is being adapted to humans. The current issues include security, privacy, a lack of experienced staff, a lengthy process, and a high price requirement. To operate with smart machines and cobots, industry 5.0 adoption is necessary in order to abide by industrial norms and regulations. Quantum computing, cognitive computing, and human-machine interaction are the three areas that industry 5.0 will focus on in the future.

Contrary to all of these expert systems that are used to build Industry 4.0, the fifth revolution will call for considerably broader cognitive abilities The current state-of-the-art in AI, that is built on Machine Learning algorithms that collect data samples to train on them and infer predictions, cannot handle Industry 5.0 difficulties where information domains are fuzzier and more complicated and explicit prior and contextual information is needed[23]. The failure of IBM's Watson in the healthcare industry is a classic illustration of the technology's existing limitations in fields involving complicated workflows and high levels of analytical complexity. In generally, training and testing-based techniques that draw out implicitly information from data must be effectively paired with explicit knowledge, which may be categorized as ontologies, formulas, laws, and even in the form of natural language.

A new computer paradigm will be required to start the next technology revolution that will enable the development of Augmented Intelligence, much like how GPUs accelerated Deep Learning and ultimately produced a global revolution in AI. Yet, existing quantum AI is characterized as an important acceleration of training phase, which is not in line with the primary objectives of augmented intelligence[24]. Quantum computing is demonstrating a tremendous potential to undertake simulation and optimization tasks. Aside from that, neuromorphic computing seems to be the most potential technical advancement for making the ground-breaking advancements in artificial intelligence.

- It is necessary to understand how an autonomous system can include ethical standards before integrating sophisticated abilities into industrial management.
- The autonomous system paradigm requires sufficient ethical behavior validation and verification.
- Transparency in implementing operations, quick manufacturing, and competent production may be important in the overproduction issue.

Hence in summary, in an autonomous system must be clear ethical behavior solutions. Industrial expertise in especially face problems with adaptation and application.

8. Critical challenge faced in blockchain enable AI for Industry 5.0

The following lists the challenges in faced in blockchain enable AI for industry 5.0 It is simpler to ignore the possible difficulties as industry 5.0 approaches. For industry 5.0 developments to be successful for the business, the problems are being recognized and addressed.

- People must get competency abilities since they will be interacting with sophisticated robots; they must learn how to cooperate with robot and smart machine manufacturers. For human workers, acquiring technical skills is a problem in addition to the soft skills that are needed. The new roles involve challenging activities requiring a high level of technological expertise, such as handling translation and programming to the industrial robot.
- Human workers will need to put in more time and effort if modern technology is adopted. For industry 5.0, collaborative robots, artificial intelligence, real-time data, and the IoTs must be implemented in customised software-connected enterprises.
- Investments are necessary in cutting-edge techniques. The price of UR Cobot is high. More expenditures are associated with training human workers for new jobs. Companies are having trouble upgrading their production lines for industry 5.0. Implementing Industry 5.0 is expensive because it calls for sophisticated machinery and highly qualified workers to boost output and efficiency.
- Industry 5.0 faces a security challenge because ecosystems trust is essential to its success. In order to interface with a wide range of devices and defend against potential applications of quantum computing, the industry uses authenticating. Industry 5.0's use of automation and artificial intelligence presents challenges to the company, necessitating the need for reliable security. As Industry 5.0 applications are heavily reliant on ICT systems, stringent security standards are necessary to guard against security risks.

According to recent developments in a variety of network techniques, AI has the power to digitally revolutionize any sector of business and industry. The lack of implementing ideas, however, is one of the fundamental problems with AI. To thrive in a corporate setting, a strategic strategy is required, such as the identification of developing areas, beneficial objects, persistent failures, etc. Company managers, supervisors, and technical teams need to be well-versed in the abilities, advancements, and restrictions of AI while also keeping an eye on the current problems that AI is currently facing in order to understand the aforementioned challenges[25]. Companies can easily identify the areas that AI can improve if they keep up with these developments on information working styles connected to AI. Any network has a high degree of complexity, and the incorporation of AI into communication systems has increased the complexity of schemes even further. With case-specific industrial network ML, the remaining objectivities are disregarded in favor of the single aim. Also, with sufficient resources, IoT devices can send data directly to higher levels without the need for any intermediate calculations[26]. As a result, WSN (wireless sensor network) and IoT embedded AI systems need to achieve specific goals while juggling additional constraints including storage, connectivity, computation, and latency. It can be useful to utilize AI in one layer or it might facilitate optimization in another layer.

9. Future research opportunities for blockchain enable AI for industry 5.0

The following lists the difficulties in the research and potential directions in the future.

Regulations and management: An important barrier is the present industrial control technology' centralized process. These systems are larger and more complicated to scale for corporate operations. As a result of the data having to be rerouted in the event of a central system assault, network latency and CPU consumption go up[27]. Authorities in a centralized system may extensively investigate any transaction performed by a user. In a decentralized network, the transaction is verified by a peer-to-peer connected system set. However, the P2P communication guidelines ought to apply to all programs. One alternative strategy for assuring greater control across apps and service end-points is the development of a unified web application where information is transferred via APIs (Application Programming Interface).

Scalability: These days, the BC network stores and validates all transactions. As a result, the BC network's ledger grows rapidly, which increases the time required to traverse every block in the chain. Just a certain amount of transactional data may be handled by each set block size. According on the consensus technique applied to assess the freshly generated block, the block size and adding time of the BC change. As an illustration, some public BC ledgers can only process 7 to 8 transactions per second. Millions of transactions take place in real-time industry applications, which complicates BC adoption and creates a scalability problem[28]. Depending on how the application will be used, the problem might be solved by creating sidechain ledgers that can move transactional data between chains. Another strategy is to promote BC sharding, which creates little ledgers of BC that are under the control of a BC authority. Making ensuring that the sharded BC follows a fair consensus principle is the only thing that needs to be done to ensure that certain apps are not given preference and that transactions are appropriately sorted in the main chain.

Managing expectation: In the commercial context, building trust is essential because an attacker could stop a persistent data leak that makes it impossible to have confidence in anyone using the systems. BC can be used in these circumstances to avoid tampering and promote confidence because the ledger is permanent and the blocks are created using cryptographic hashes. A statistical study of trust computation is necessary if the nodes engage in risky behavior, which is a difficulty with respect to trust measurements, which are important for real-time system management[29]. A reputation-based BC design has been proposed in a recent study, which establishes a consensus based on the miner's reputation and assigns a reputation score to recently added transactions.

Establishing governance: Any corporate organization's first priority is the protection of sensitive information, and the security needs differ depending on the application. In the case of cloud monitoring, where we examine attack signatures and identify vulnerabilities, authorization and authentication are key requirements. As a result, the attackers are unable to access information without authorization or alter it. Vehicle systems face a serious problem with certificate generation, and BC permits trusted certificate generation. As sensitive patient information must not be released to unapproved parties, privacy is the top necessity in the healthcare industry[30]. A single, integrated BC framework insufficient to meet all of Industry 5.0's requirements. One approach is to create unique BC networks that can serve and handle the particular needs of various verticals.

Storage and transaction cost: Even if it provides confidence and chronology in industrial activities, establishing BC requires considerable resources. Also, communication costs increase as sensor nodes make connections with other nodes. There are presently no set universal cost addressal recommendations because most methods just optimize the cost component. As a result, interesting research areas include creating a uniform standard set of protocols for the BC network that might reduce the cost of communication. Nevertheless, this would be in stark contrast to the specific requirements of the application. Other strategy is to develop inexpensive SCs that can be kept in the memory of the sensor node and deployed by the sensor node itself as soon as it has gathered sufficient information. This has a major impact on automation and lowers costs in industrial applications.

Energy usage: Energy consumption is a constraint on sensor-driven industrial applications. Lately, a potential solution for this issue has been suggested: private, permissioned BC networks. The private network, however, employs its unique consensus method to manage the power consumption of sensor operation, which could compromise its security. Once again, these consensus systems adopt a centralized or semi-distributed approach, where a central validator node manages the mining needs. This makes the whole trust measuring process an important use case. As a result, researchers have recently had a change of heart about the idea of recommending verified trustworthy BC solutions in permissioned and private networks, in order to attain the perfect balance of energy cost vs. security trade-off in deployed applications.

Smart hospital: Industry 5.0 wants to create an intelligent, real-time hospital. The technique can provide options for remote monitoring in the healthcare sector. It’s essential for raising doctors’ quality of life. During the COVID-19 epidemic, adopting this smart healthcare system allows doctors to focus on affected individuals and provide useful information for better treatments. The COVID-19 outbreak aids both medical students and students in other academic fields in obtaining the necessary medical training. Natural language processing, genetic data, and medical imaging are all applications of machine learning (ML). It is concentrated on the identification, diagnosis, and predictions of diseases.

Manufacturing industry: A new production model known as “Industry 5.0” is one that emphasizes both human and machine interaction. Industry 5.0 is all about utilizing the interaction between more accurate machines and human creativity. It creates procedures that repurpose and recycle the resources in order to make production sustainable. Reducing the manufacturing sector’s environmental effects is also necessary. To maximize resource efficiency and waste reduction, additive manufacturing is necessary to boost personalisation[31]. By relieving human workers of monotonous chores, Industry 5.0 is transforming production processes all over the world. Brown and Wobst provided evidence that supply chains and factory floors are being profoundly altered by intelligent robots and systems. Smart manufacturing makes it possible for designers to safeguard the design files of manufactured products by keeping them in the cloud with stringent access restrictions and utilizing production resources spread across several regions.

Supply chain management: Supply chain 5.0, according to Nguyen et al., emphasizes the value of cooperation between humans and intelligent devices like COBOTS. The goal of Industry 5.0 is to meet the customers’ demands for extreme customisation and customisation, which call for a combination of machine skill and human creativity[32,33]. This was added to each product for supply chain management in massive production volumes of uniformity, and it presents a challenge where the robots require enough supervision. Babamiri et al. contend that personalized and customized products can be produced without a human touch. It also guarantees the supply chain’s flawless end-to-end operations, including the choice of raw materials based on an understanding of the demands of each customer’s unique personalisation and customization[34,35].

Human engagement and automated, intelligent digital ecosystems are intended to be combined in Industry 5.0. In this method, human factors are used in order to create customized end-user experiences and effective workflows. A complete description of such future research [35,36] is depicted in **Figure 3**.

Figure 3. Applications of Industry 5.0.

10. Conclusion

Maximizing both human and machine productivity is the aim of the Industry 5.0 concept. Considering BC's possible function as a catalyst for fostering trust in Industry 5.0, the recommended poll provides readers with insightful information. We highlighted about the supporting mechanisms that helped shape the Industry 5.0 vision and proposed that BC be acknowledged as a important security enabler in the Industry 5.0 practices. In order to cover Industry 5.0 verticals including smart manufacturing, healthcare, digital twins, cobots, and others, we were able to structure our conversation using a recommended BC-assisted reference model. Finally, by automating transactional payments via SCs, BC-enabled Industry 5.0 will increase end-user happiness while defending the CPS perimeters.

We provided an Industry 5.0 solution taxonomy of supporting verticals along with any outstanding issues and challenges that came up during actual implementations. Additionally, we offered open criticisms of BC and future strategies for mitigating the criticisms, arguing that BC is not a universally applicable solution. Lastly, a comprehensive case study on the creation of digital twins helped by BC for Industry 5.0 is presented. The proposed case study's security analysis, which we gave, supports its applicability in real-world settings. Ultimately, the survey's findings and key takeaways are provided. With the shared information provided to AI models being verified on distributed ledgers, we hope to create a BC-based trusted architecture for extensive human-robot interaction as a component of the future scope. The fundamental framework would be explored, together with the threat and network models, and reliable AI solutions will be shown.

Conflict of interest

The authors declare no conflict of interest.

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