Review on Blockchain for Industry 4.0 Applications & Architecture for Effective Implementation

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Abstract

Industry 4.0 is considered to one of most recent developments, and is drastically changing perception of manufacturing industries especially in the developing nations. It is essentially a synergic integration between hardware (e.g., machines) with software using internet technology so that process monitoring over entire process, and relevant data analytics to improve overall performance of process can be satisfactorily achieved. Overall implementation of Industry 4.0 will transform existing manufacturing industries into smart manufacturing. An implementation of Industry 4.0 also includes fundamentals of Industrial Internet of Things (IIoT), cyberphysical systems, and Internet of Things (IoT) that further focus on acquisition of various types of data from different hardware used in respective manufacturing process. The data is usually streamed to centralized server, and has challenges related to maintaining privacy as well as security. Another disruptive technology, Blockchain can be explored in implementation of IIoT, in turn, Industry 4.0 to maintain higher level of security and privacy. More than 35 research papers were reviewed for getting an insight about implementation, and related challenges faced during implementation. It was observed that specific architecture is also required for effective implementation of Blockchain in Industry 4.0 application especially connected to manufacturing domain. An architecture focused on hybrid approach that further acquires the data, streams the data to local server followed by insertion into Blockchain to avoid latency of time as well as too much financial implications on transactions.

Keywords

Industry 4.0, IIoT, Blockchain, Cyber Manufacturing Systems

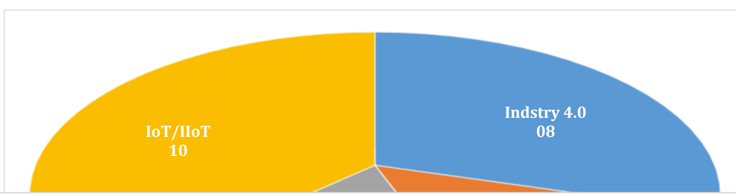
Introduction

Industries have been revolutionized drastically since Industry 1.0 (focused on conversion of raw material into product using machine) to Industry 4.0 (focused on an integration of hardware and software using internet technology) while passing through Industry 2.0 (focused on conversion of raw material into product using machine with higher productivity) as well as Industry 3.0 (focused on an integration of hardware and software to achieve productivity).

A new industrial paradigm referred to as Industry 4.0 serves as symbol for the revolution in industry IV. Modern manufacturing paradigm disrupts the previous three industrial revolutions and is typified through virtual, digital, and intelligent performance in major sectors. The industry 4.0 design principles, basic to the new industrial model comprising an integrated factory structure and potential technologies in different industry activity sectors, guarantee the creative performance of this new industry [1]. The term "industry 4.0" has grown in popularity to refer to the trend of production environments becoming more automated and digitalized. "Industry 4.0" made its debut in 2011 at the renowned Hannover Fair. It was a German industry project approach. The phrase was subsequently accepted at the 2015 World Economic Forum (WEF) in Davos, Switzerland, and it also surfaced in Klaus Schwab's book, "The Fourth Industrial Revolution," as the WEF's founder and president. Industry 4.0 can be defined as a revolution in the digital realm [2]. The unification of all the elements has gained widespread acceptance in literature and gained popularity perhaps the fourth industrial revolution, or Industry 4.0 technology like cloud computing, data analytics, additive manufacturing, cyber-physical systems (CPS), Smart manufacturing, IoT, etc. **[3].**

One of primary functions that can be achieved by implementing Industry 4.0 in any typical industrial environment is acquisition of various types of data from different hardware or machine, and stream the acquired data to server through internet technology. However, data always need to be acquired, streamed and stored with appropriate measures related to privacy as well as security. Currently, this is mostly maintained by typical arrangements of maintaining security (e.g., two-steps verification) however implementation of Blockchain (one of the disruptive technologies for providing secure, private, peer to peer, trustworthy security mechanism) is yet to fully explored specifically in the domain of Industry 4.0.

This work is primarily focused on implementation of Blockchain for maintaining higher level of security and privacy for Industry 4.0 related technologies. More than 35 research articles have been reviewed for getting better insight about its implementation. Categorization of this review as well as year of publications are shown in figure 1 and 2.



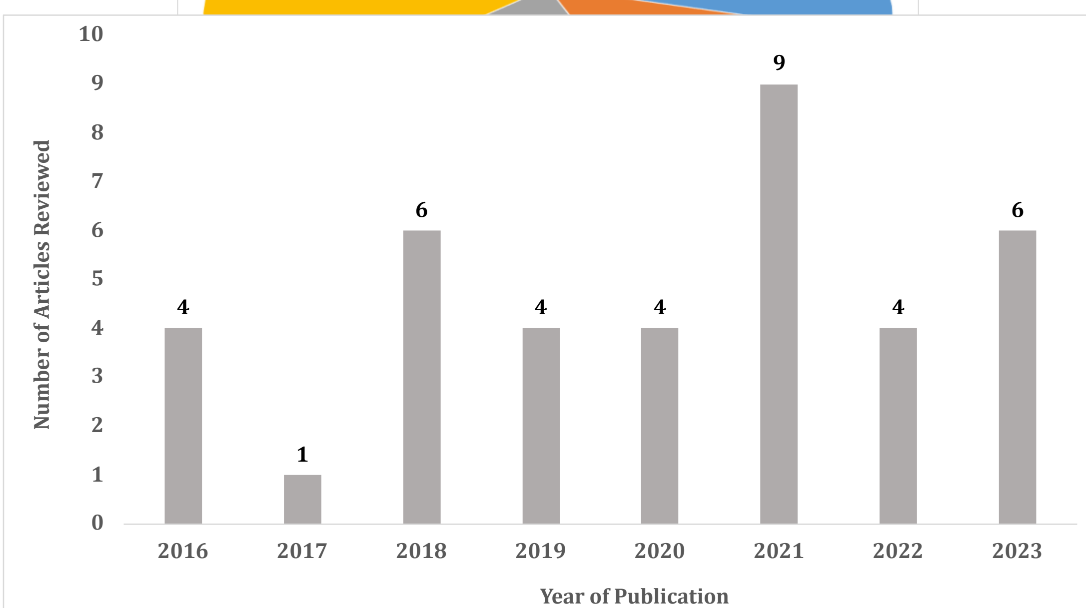


Figure 2: Distribution of research conducted – year wise

Detailed findings observed from these literatures are discussed in following section.

Prior Work

This study discusses the concept of Industry 4.0 and the importance of capacity optimization in production processes. It offers a capacity management mathematical model that is based on two separate costing models (ABC and TDABC). This study suggests a decentralized network of processing and manufacturing nodes to allow for transparency, verification, and automated contracts using smart contracts. It introduces a system framework called FabRec for a decentralized manufacturing ecosystem and highlights the specific uses for blockchain technology for manufacturing services. In addition, the structure of smart contracts in FabRec and the nodal data exchange within the system are discussed. This study compares different mining algorithms and their implications in blockchain systems and concludes by discussing the suitability of blockchains for real-time data transfer and manufacturing decision-making [4].

Centralized corporate networks and third-party trust activities in manufacturing are the subject of another study. To improve security and scalability, this study proposes a dispersed peer-to-peer network configuration called "BCmfg" based on blockchain technology in our work, we highlight the advantages of blockchain technology in various applications such as logistics, healthcare, and data storage. The proposed architecture includes five layers and utilizes IoT for smart factory visibility and traceability. In addition, the architecture includes blockchain clients in different layers and smart contracts for secure data sharing and on-demand services. The promise of blockchain technology to lower operating costs, produce safe transaction records, and enable transparent ledgers is highlighted in this paper. By incorporating blockchain technology into smart manufacturing, the suggested architecture seeks to increase the adaptability and agility of industrial systems [5]. Mould redesign (MR) projects involve multiple sections and tasks with high requirements. Cross-enterprise cooperation in MR is time-consuming and complex. Knowledge-based expert systems and cloud manufacturing can be used for effective knowledge sharing.

The proposed system architecture includes enterprise, knowledge resources, blockchain, and application layers. The private cloud is used for standardized knowledge sharing. Feature extraction methods, such as TF-IDF and KNN-based inquiry methods, are utilized. Smart contracts and blockchains are used for sharing and verifying knowledge. This paper discusses how to include digital twins into productive cyber-physical cloud manufacturing systems (CPCM). A novel approach to creating cloud-based digital twins (CBDTs) that optimize interactions between physical machines and human users while minimizing the amount of processing power needed in the data center was devised and explored.

The MTConnect protocol was optimized for data capture in manufacturing processes, minimizing communication latency and overhead. In several experiments, the CBDT method demonstrates exceptional performance in comparison to current techniques. An MTConnect-based cyber-physical cloud manufacturing system's idea and operation are also covered in this study. In this work, information models for various kinds of 3D printers are presented along with the system architecture for cloud-based manufacturing digital twins equipment. The approach of CBDT is contrasted with other methods in terms of delt for transmitting datasets to the server [6]. The application of blockchain technology to Industry 4.0 to secure smart production is covered in this survey. It identifies issues related to cybersecurity, proposes solutions for data availability and security, and proposes the use of smart contracts as well as digital twins for manufacturing processes that autonomously organize. In addition, it highlights blockchain's potential to assist in the tracking of business data and to improve data analytics. Future research directions include the development of evaluation protocols for blockchain cybersecurity, highly efficient consensus algorithms, data mining, and privacy protection [7].

Industry 4.0 has chances thanks to blockchain technology, which might improve information security and lead to the development of smart factories. It can lower risk and improve process safety, but significant effort must be made before it can be put into use. The use of blockchain technology could lower energy usage, facilitate decentralized transactions and knowledge sharing, and optimize manufacturing processes. It can be applied to appropriate management in Industry 4.0, data storage, and supply chain management. Numerous reviews and studies on the uses and advantages of blockchain technology in Industry 4.0 have been published [**8**].

Cyber-physical systems (CPS)

Data from linked systems is transformed into predictive and predictive operations through the use of cyber manufacturing, a transformative system. Scalable analytical technology platforms are required in cyber manufacturing, but there are no standards for seamless connectivity. The transition to cyber manufacturing will be made possible by standardization, trustworthy cyber security, and a global platform for analytical technologies that can be expanded. Industry 4.0 is a new program supported by Germany that aims to change cyber-physical production [9].

To improve transparency and traceability, the use of blockchain technology in the production supply chain is examined in this document. By enabling decentralized, secure, and immutable record-keeping of product information, blockchain guarantees the accuracy of data. Digital identity and smart contracts limit access and updates only to authorized parties. This technology makes it possible to record important data, such as time, location, and product information, throughout the whole supply chain. To illustrate the practical use of blockchain using digital identity creation to prevent "blood diamonds" from entering the market, the document highlights real-world examples such as Ever Ledger, a company that tracks diamonds in the jewelry market, also known as asset tracking. To highlight the potential benefits of blockchains, this document highlights how blockchains can enhance the control of financial transactions, product tracking, and quality control in the supply chain [10].

This paper deals with cybersecurity threats and the importance of regulatory standards. It highlights the significance of big data analytics in extracting valuable insights from production data. This conclusion emphasizes the need for standardized regulations, the importance of cultivating cyber talent, and collaborative efforts between manufacturers and educational institutions for successful cyber manufacturing implementation. This study introduces the concept of cyber manufacturing, a transformative approach in the manufacturing industry. With a focus on the function of CPS in intelligent communication and interaction, this study examines the development of manufacturing overall.

IoT, big data analytics, and CPS are examples of enabling technologies that are covered. This paper deals with cybersecurity threats and the importance of regulatory standards. It highlights the significance of big data analytics in extracting valuable insights from production data. This conclusion emphasizes the need for standardized regulations, the importance of cultivating cyber talent, and collaborative efforts between manufacturers and educational institutions for successful cyber manufacturing implementation [11]. This highlights the impact of blockchain technology on the manufacturing industry and stresses its role in creating an automated and smart environment. Blockchain is considered to be a solution to the lack of autonomous, decentralized decision-making and secure real-time communication in smart manufacturing systems. This study introduces the concept of a blockchain-driven cyber-physical production system (BDCPS) in collaboration with the Internet of Things (IoT). This paper highlights the advantages of blockchain, such as decentralization of power and secure, transparent distributed ledgers.

This paper presents a small-scale implementation of blockchain with IoT for machine communication and maintenance as a validation of its potential in smart manufacturing. In addition, the discussion touches on challenges in IoT interactions and how blockchain addresses trustless interaction. This paper provides an overview of blockchain as a peer-to-peer technology for creating digital ledgers and emphasizes its decentralized nature governed by consensus [12].

Smart manufacturing

The quantity, speed, and diversity of advanced data connected to big data are related to the leverage from smart manufacturing. The majority of blockchain applications rely on smart contract-based asset transfers and information distribution across networks, which are seen to be perfect for industry and company processes. In Industry 4, smart manufacturing is the primary focus. The public and private layers are the two primary blockchain layers in this system that are used to carry out the manufacturer's transaction.

In order to oversee the manufacturing process and maintain control over the circumstances to lower the process's fault rate, the manager first communicates with the distributor, manufacturer, and supplier. Rules for the manufacturing process are established in smart contracts. The data kept on the blockchain is contained in each stratum. The private layer's primary focus is the manufacturer's product distribution strategy. Initially, the manufacturer decrypts the supplied data before distributing it in the private layer. The data mining procedure is the initial stage in managing and verifying the transaction dataset. The dataset is then kept in the blockchain's sequence structure, and the transaction is verified.

The study's primary contributions include real-time monitoring based on Internet of Things environmental sensors and predictive analysis based on manufacturing system fault diagnosis. The second decade of the new century has seen the advancement of industry development, which has led to the improvement of the next generation of analytics - Big Data Difficulties and the Revolution in Smart Manufacturing. Increasing device complexity required a revolution in manufacturing processes, which was the first step towards improving smart manufacturing's decision-making process.

Predictive smart manufacturing gains more from data-driven marketing when a manufacturer can recognize customer preferences and product defects in real time with the use of big data research. Enormous volumes of data in the industrial sector can be processed and stored by some big data technologies. Applying big data technologies to healthcare has shown good results, according to some research. For instance, real-time data monitoring in the healthcare sector was made possible by sensor data produced using IoT technology. Patient data retrieved from sensors is saved by the suggested system using a combination of Apache Kafka and MongoDB.

A cloud-based parking system including the Apache Kafka method is suggested. An increase in the number of customers can be handled by the system by handling a lot of sensor data. Intelligent Production Blockchain technology is revolutionary in terms of fault tolerance, data transmission, transparency, and security [13]. For SMSs, blockchain is a useful invention. Over $300 million was spent globally in 2019 on blockchain technology in manufacturing. The formats, capabilities, and attributes of blockchain-enabled SMSs are different from those of regular SMSs. Blockchain applications don't always work well. The biggest obstacle to the successful adoption of blockchain is cost. Scalability solutions must strike a balance between intricacy and ease of use. Component, structural, and functional complexity all contribute to the overall complexity of BSMSs. There are issues with cost, scalability, interoperability, security, and privacy with blockchain applications in SMSs. Legislative authorities ought to pass laws that promote positive conduct. The paucity of research on BSMSs can act as a foundation for more investigations [14].

The potential of blockchain technology to improve smart industrial systems is examined in this survey. It draws attention to advantages including improved security, traceability, and transparency that lower production costs. It highlights how technology helps with data security, sharing, trust frameworks, and system coordination. Proof of Work and Proof of Stake are two examples of consensus procedures that improve fairness and confidence. The survey underlines blockchain solutions as addressing fundamental concerns in smart manufacturing, presenting insights from diverse research and ideas focused on performance optimization and trust enhancement. The survey's ultimate goal is to lay the theoretical groundwork towards creating a smart manufacturing system with blockchain technology that is more trustworthy and genuine [15].

Small and medium-sized businesses (SMEs) are faced with operational issues when it comes to maintaining integrity and transparency. Blockchain SMEs (B-SMEs) are a suggested answer to these challenges. B-SMEs mix blockchain, IoT, and AI/ML to boost cooperation, reduce resource consumption, and optimize efficiency. The significance of quality and the changing role of SMEs in international trade are emphasized. The essay delves into the impact of digital manufacturing on real-time synchronization and highlights the lack of standard procedures for developing manufacturing units. It is acknowledged that industrial IoT is a useful tool for fostering teamwork in large-scale operations [16].

Blockchain technology has attracted interest in various industries. The aim of the Blockchain for Industrial Applications (BIA) Community of Interest is to advance research and development initiatives for smart manufacturing and industrial applications using blockchain technology. The BIA COI provides stakeholders with guidelines, education, use case management, validation, dissemination, and communication. Interested parties may join the BIA COI by registering through GovDelivery and contributing to the GitHub repositories [17].

Internet of Things (IoT)

In short, the Internet of Things consists of physical items implanted with electrical sensors and actuators and digital devices running specific software to enable connectivity. They are all linked to a global networked environment, usually via the Internet. It is also referred to as the Internet of Everything, which includes the Internet of Manufacturing Services, the Internet of People, the Internet of Services, embedded systems, and the Integration of Information and Communication Technologies. While Industry 4.0 is not the only revolution in connection, the Internet of Things integration permits the gathering and sharing of data on a never-before-seen scale. Sector An important aspect of this industrial revolution is the internet [18].

For IIoT, this article introduces BPIIoT, a decentralized, peer-to-peer network built on blockchain. The platform aims to improve cloud-based manufacturing (CBM) by enabling access to production resources as needed without the need for a trusted intermediary. The main contributions include the integration of transferring outdated shop floor machinery to a cloud setting, the automation of machine maintenance and diagnostic tasks, and the provision of a safe and shared ledger through blockchain. This paper presents a blockchain-based dispersed, peer-to-peer network called BPIIoT for the IIoT. The platform aims to improve cloud-based manufacturing (CBM) by enabling on-demand access to production resources without the requirement for a reliable middleman. Using blockchain to create a safe and shared ledger, automating machine maintenance and diagnostics activities, and incorporating old shop floor machinery onto the cloud are some of the major achievements.

The paper discusses related work on blockchain technology, mentioning collaborations by IBM and Samsung, and presents key notions pertaining to smart contracts, blockchain, and the Ethereum network. A comprehensive overview of the proposed BPIIoT platform is given, with a focus on its possible uses in supply chain tracking, machine maintenance, traceability, on-demand manufacturing, smart diagnostics, and more. A case study of the implementation using Beagle Bone Black and Arduino Uno demonstrates an application for smart diagnostics and machine maintenance. This paper discusses the benefits of blockchain for IIoT, such as decentralization, resilience, scalability, security, and auditability, while acknowledging challenges such as CAP and blockchain trade-offs, smart contract vulnerabilities, awareness, regulation, privacy, and efficiency. The paper concludes by highlighting the promising aspects of blockchain for IIoT and identifying issues that must be resolved for broad adoption. Subsequent endeavors ought to concentrate on executing and exhibiting the BPIIoT platform in more pragmatic situations [19]. Blockchain technology solves the Byzantine General's problem and ensures the integrity of distributed systems through consensus algorithms. NASDAQ is actively involved in the development of blockchain-based private equity exchange systems and related projects.

In the case of manufacturing companies, blockchain offers real-time transparency and timestamps, which can reduce surveillance costs. Ripple Labs has implemented a remittance system using blockchain technology. The manufacturing sector's increased adoption of blockchain is considered to be a way of saving costs and increasing profits [20].

This research offers taxonomy of IIOT needs and aligns them with blockchain technology. By shedding light on theory and practice, this study hopes to aid practitioners and researchers in making decisions. The strengths and weaknesses of blockchain technology for application in the manufacturing industry are analyzed. IIOT requirements include scalability, extendibility, compatibility, and interoperability. The ability of blockchain technology in terms of data integrity, non-repudiation, and adaptability are highlighted. Future research on particular Blockchain design elements in the manufacturing sector is made possible by this study [21].

IoT is an efficient environment in which users can transmit information to the server. Industry, business, environmental engineering, mobile devices, and governance are just a few of the domains where IoT is used. IIoT is heavily discussed within Industry 4.0, and it can encourage a range of industrial uses in the fields of manufacturing, logistics, food production, and services. Blockchain technology has developed from an impersonal strategy to a reliable dispute resolution technique. Apps with smart implications, digital assets, and distributed storage are the key uses of blockchain technology, which is being embraced quickly [22].

IoT technology has connected billions of objects and people for data collecting, processing, and decision-making, expanding Internet connectivity across various application domains. The majority of industrial IoT systems currently in use still rely on centralized architecture, which makes the central entity extremely computationally demanding and susceptible to single-point-of-failure assaults.

Blockchain technology might completely transform IIoT applications and systems in terms of interoperability, scalability, and security. This research offers an extensive analysis of current developments in technology and architectural design to tackle these issues.

The goal of Industrial Internet of Things (IIoT) is to incorporate new technologies—like robotics, big data analysis, machine-to-machine communication, smart sensors, and artificial intelligence—into established industrial processes. IoT technology is expected to lead to the creation of next-generation smart system development and the emergence of new smart industrial businesses. However, an increasing number of IoT devices generate huge volumes of data, increasing the expenses associated with operations and administration. Numerous connections between devices increase security and privacy, privacy, security, and fault tolerance among device manufacturers and smart factories. Decentralized solutions based on blockchain create data that is immutable and does not need to be managed and controlled by centralized organizations. The industrial and academic sectors have both given the emergence of blockchain technology a great deal of attention [23].

The Blockchain is a cutting-edge technology that has gained significant traction. Its decentralization, immutable storage, and encryption capabilities offer smart industrial frameworks enormous promise. Over the past several years, several industrial Internet of Things (IIoT) applications have surfaced, and both industry and academics have shown a significant deal of interest in blockchain technologies. To uncover the immense possibilities of blockchain technology for the Internet of Things, we offer an extensive overview of security concerns, blockchain structures, and industrial applications. The comparison of current state-of-the-art surveys of blockchain technology for IoT/IIoT applications is the first section of this article. The features and security concerns of each tier of the IIoT reference architecture, which consists of four layers, are outlined. We evaluate the potential of blockchain technology by taking into account its salient features, designs, consensus algorithms, and deployment platforms to address these issues [24]. The Internet of Things (IoT) has transformed personal computers, education, communication, and business globally. In 1999, while working for Procter & Gamble, Kevin Ashthon came up with the term "Internet of things." IoT gained traction in real-time sensing, efficient information sharing, energy and cost reduction, and increased productivity. The concept of incorporating IoT has been growing in the domain of autonomous vehicles (AVs) (SDTs). For driverless technologies to function safely and effectively in dynamic, complicated contexts, research is being done. IoT applications are being used more and more in a variety of industries, including home, agricultural, forestry, climate and meteorological research, and public and personal health. IoT applications are covered in brief in this article and are divided into seven categories of IoT systems [25].

This explains the idea of the IoT and highlights how crucial information connectivity is to Industry 4.0. Web 1.0 to Web 2.0 transition is covered, and the terms interoperability and connectivity in the context of IoT are introduced. Some research studies suggest direct connections between blockchains and IoT systems, highlighting role of blockchain technology in solving safe data interchange. The merits of blockchain technology for integrity and dependable distribution are discussed, along with the utilization of hybrid storage solutions.

The technological developments in data-sharing protocols and the function of blockchain in secure data exchange and commerce are also covered in the text. Three interconnected layers make up the architecture design, which supports hash string routing and encrypted data storage by leveraging the IPFS data transport protocol [26]. In industrial supply chains, blockchain technology can efficiently handle a variety of data-related issues, such as product visibility, product traceability, counterfeit item identification, and a decrease in paperwork and administrative burdens. The goal of this study is to close the significant research gap regarding the implications of blockchain technology for the manufacturing industry. A thorough content analysis of 117 pertinent publications was carried out using a two-stage systematic literature review process. According to the report, blockchain technology can contribute to the development of decentralized manufacturing systems and enhance industrial supply chains' efficiency, security, and transparency. Using centrality and co-occurrence of terms, the study also identified important research clusters. It also discovered that IEEE Access, Computer Standards and Interfaces, and Applied Sciences were the most often used sources of articles. The research also emphasized the words "cryptography," "decentralized," and "manufacturing" and their relevance within the field in the network [27].

1. **Supply chain management /Logistics**

To ensure the effectiveness of medicines, verifying their authenticity and maintaining a temperature range is crucial. A smart transportation box is needed to maintain a constant temperature and record any changes into a pre-programmed sensor. A cold chain framework is essential for the transport and storage of medications that react to heat, such insulin or vaccinations. Blockchain technology can be considered to be a strong solution for building confidence among stakeholders among the supplier chain. All unchangeable sensor data is stored by blockchain technology, which makes it a safe solution for the healthcare sector. Sensors can collect temperature data during transit, and a blockchain contains a QR code hash storage [28]. The efficiency of decision-making and the dependability and credibility of supply chain transactions are both positively impacted by blockchain technology. It improves monitoring processes, identifying problems, forecasting trends, and making decisions in concert with other technologies like big data analytics, artificial intelligence, and the Internet of Things. Manufacturers use blockchain technology to track a product's carbon footprint, minimize waste and pollution, and maximize the use of energy and resources. Blockchain facilitates direct communication between suppliers, merchants, producers, and customers, which raises the productivity and quality of manufacturing. Furthermore, blockchain helps manufacturers improve human rights, working conditions, and social responsibility [29].

The study looks closely at supply chain blockchain applications, highlighting social, economic, and environmental factors while evaluating real-world examples. It lists Ethereum and Hyperledger Fabric as well as other well-known platforms. It also talks about how blockchain was created to solve the issue of double-spending and that it is a distributed ledger with encrypted entries. Supply chain intricacies, principal motivators, and obstacles are examined, accompanied by instances incorporation of blockchain technology in the manufacturing industry (e.g., Maersk) as well its advantages in the insurance industry. The paper concludes that blockchain may significantly change information handling in supply chain supervision and planning, and also emphasizes the usefulness of blockchain in banking and finance [30].

2. Operations management and manufacturing

The aim of this research is to determine the present barriers facing the industry and investigate the potential applications of blockchain technology in manufacturing and operations management. Semi-structured interviews with professionals in the field and academics were used to conduct qualitative research. Blockchain technology has potential applications in the automotive, pharmaceutical, and mechanical engineering industries. Experts concur that blockchain technology can greatly advance the idea of production networks and facilitate the development of new networks for operations management. Standardization and management support are crucial for successful collaboration and network establishment. Technology obstacles, such as a lack of technical knowledge and awareness, must be removed in order to properly integrate blockchain in manufacturing and operations management [31]. The increasing automation and connectivity of the manufacturing industry demands efficiency and competitiveness. Blockchain technology has been recognized as a solution for managing large datasets, and diverse interfaces, and ensuring safety and reliability. Using the ProKnow-C methodology, a study assesses The blockchain's potential for use in manufacturing, identifying trends and opportunities.

The ProKnow-C methodology is designed for systematic analysis in research. It consists of three main stages: bibliographic portfolio selection, which involves the definition of research axes and keyword breakdown for database searches; bibliographic portfolio analysis, which encompasses the examination of impact factors, keyword occurrences, and relevant authors within the selected works; and systemic analysis, which focuses on the content of selected works and identifies issues, proposals, and research gaps. This method offers a structured and effective approach for exploring and understanding the landscape of academic literature, facilitating insights into trends and opportunities in a particular field, as well as insights into blockchain's potential for manufacturing and identifying areas for further research [32].

This systematic review explores the intersection of engineering and manufacturing with blockchain technology. Through content analysis, the included studies were categorized into themes such as blockchain for building information models (BIM) and additive manufacturing, such as 3-D printing and direct digital manufacturing, improving communications, cloud manufacturing, and scalability/security enhancement. The review shows that there is a lack of empirical analyses on how well blockchains serve engineering and manufacturing activities, highlighting the need for further research to assess the practical implications of blockchains in these critical sectors [33].

Challenges

I. Knowledge of Imperfect Data:

The data preparation process involves data cleaning, transformation, integration, and reduction. Data transformation involves the conversion of data into the same units and the unification of data from different sets. The data integration should retain all information collected in the integrated dataset. Data reduction involves selecting attributes and filling in missing data. To define the intrinsic dimensionality of the collected data set, attribute selection is performed. Reducing data improves the reliability and practical applications of the model [34]. Blockchain technology has a disruptive potential and can be applied in a wide range of industries. Applications include cryptocurrencies, smart contracts, crowdfunding, prediction markets, energy markets, smart buildings, supply chain management, and digital product memory. Although there are problems with scalability and technical constraints, blockchain has the potential to change many industries. The possibilities and difficulties of blockchain applications in the industrial sector are covered in this paper. To fully capitalize on the potential of blockchain technologies, a more thorough examination of business procedures in the industrial sector will be required in the future [35].

A new paradigm called "cloud manufacturing" aims to meet the growing demands of the industrial sector. To assess how the survey was doing, a systematic literature review was carried out. Realizing and making available all kinds of manufacturing resources as services is known as "cloud manufacturing". The key characteristics of cloud manufacturing include service management, collaboration work, and system integration. Future research should focus on knowledge management, data management, and enterprise systems integration. Results from Web of Science, Scopus, and other related databases should be included in the literature search [36].

II. Privacy and Security

Scalability is increased by sharding technology, which lets certain nodes handle particular transactions. Because of its distributed connection features, blockchain is employed in IIoT for data security. A blockchain-based IIoT data security sharing system tackles concerns about fairness, privacy, and trust. Blockchain-based data-privacy security architecture for IIoT makes use of Merkle trees and data blocks. The security and dependability of blockchains depend on consensus mechanisms and reward systems that are based on node behavior. Time delay and throughput are crucial variables to consider when assessing how well blockchain algorithms work. An analysis of TPS under various trading volumes reveals that the RPBFT algorithm outperforms the PBFT algorithm in terms of TPS [37]. An approach that incorporates coded sharding blockchain technology to address the Industrial Internet of Things (IIoT) scalability and data security issues. It recognizes that consistency and scalability issues in IIoT are not adequately addressed by the blockchain solutions available today. Scalability issues are addressed by the suggested technique, which makes use of coded sharding to improve fault tolerance and lower storage load. To improve data storage and verification security, a cryptographic accumulator-based storage system is also presented. Studying the needs for IIoT, building an IIoT storage architecture using a blockchain with local repairable code (LRC) sharding, and using bilinear accumulators to solve security concerns are some of the contributions. In IIoT operations, the whole framework guarantees data security, scalability, and reliability [38].

Architecture

The creation, testing, and design of middleware software systems for distributed CMaaS platforms based on Ethereum are covered in this study. It is suggested to create a revolutionary hybrid blockchain architecture that would allow massive industrial data streams to be transferred and stored immutably on global BigchainDB nodes. According to the study, Ethereum transaction costs and a considerable number of computing steps can be decreased thanks to the hybrid architecture's design. A machine learning-based time series inference model is presented to predict Ethereum gas prices, enabling smart contracts on the CMaaS platform to reduce transaction costs. Additionally covered are the creation of blockchain-based CMaaS platforms and manufacturing system architectures focused on Digital Threads (DT). Additionally covered are the creation of blockchain-based CMaaS platforms and manufacturing system architectures focused on Digital Threads (DT). The performance of learned machine learning models in predicting Ethereum gas prices is assessed; the Random Forest regressor model demonstrates the highest accuracy [39].

It is revealed that several researchers have explored use of blockchain technology in Industry 4.0, and IoT/IIoT as well as extended to development of cyber physical system as well as in smart manufacturing systems. However, specific architecture or framework that provides better insight about implementing Blockchain in Industry 4.0 by overcoming existing challenges related to latency in time for real time monitoring as well as in higher financial implications. Specific architecture that might address the challenges mentioned above especially for the Industry 4.0 applications are discussed next.

Proposed Architecture

Proposed architecture (figure 3) that will provide a road map for implementing Blockchain for Industry 4.0 applications, and will provide better security as well as privacy in acquisitioning, streaming and storing the data for providing real time monitoring as well as for providing data analytics.

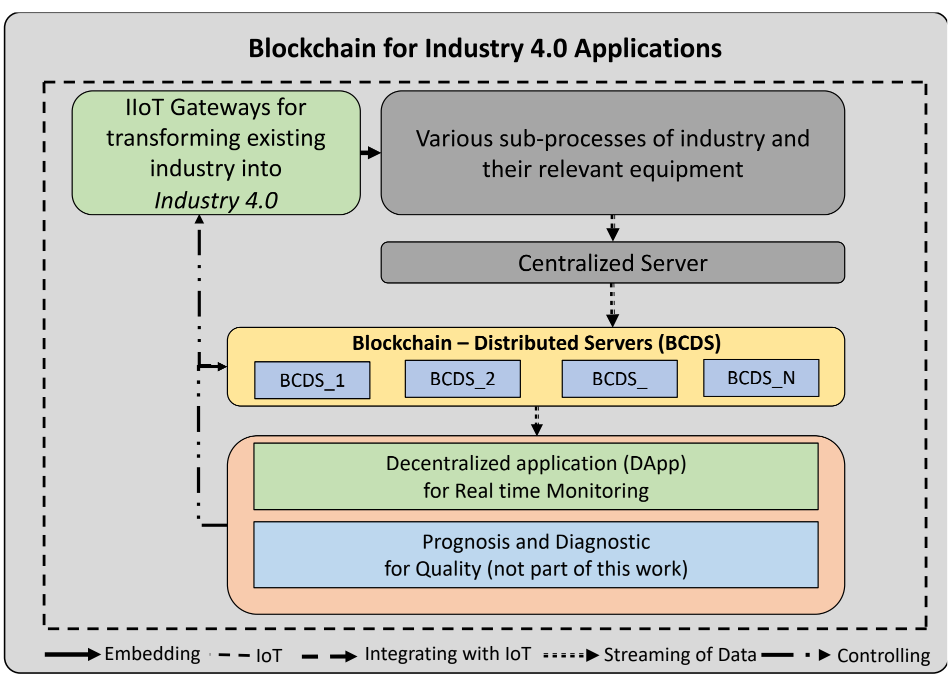


Figure 3: Proposed architecture for integrating Blockchain for Industry 4.0 applications

It is essentially to propose for transforming existing manufacturing industries into SMART manufacturing industries especially in the developing nation as it is not feasible to replace existing equipment or hardware that are available with smart machines. Therefore, it is proposed to develop specific IoT gateways so that existing machine can be transformed into smart machine for acquiring various data from it.

Most of the research work was mainly focused on acquiring data, and directly stream it to the decentralized server however it is very challenging to stream the data directly to decentralized server as lot much amount of information is acquired from many machines parallelly. In this case, financial implication will be very high as data from various machine will be streamed to Blockchain. At the same time, latency in time is also very high especially if data will be used for real time monitoring on DApp. In order to overcome these challenges, proposed architecture will have provision to stream the data initially to centralized server, and followed by streaming the data to Blockchain after specific interval. This interval will vary from industry to industry as well as can also be varied from machine to machine.

Conclusions

Industry 4.0 is considered to be one of most advanced technologies of recent time, and has key element to provide real time monitoring through acquisition of critical data that can be collected by various machine associated with respective industry. However, literature review has revealed that implementation of Industry 4.0 in more rigors way led to issues related to maintaining security as well as privacy of acquired data. Integration of Blockchain will assist in overcoming these challenges however existing architecture of Blockchain will lead in other issues related to latency in time as well as in financial implication for implementation. An architect focused on overcoming this kind of challenges has been proposed, and can be explored for various applications of Industry 4.0 in futuristic implementation. This will surely help in implementing Industry 4.0 with desired level of security as well as privacy.

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