2581-4575
International Journal For Recent Developments in Science & Technology
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SCALABLE AND SECURE MIDDLEWARE ARCHITECTURES FOR SMART MANUFACTURING IN THE ERA OF INDUSTRY 5.0

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Abstract

This work is in the context of the shift to Industry 5.0, which would call for a synergy between advanced technologies like IoT, AI, edge computing, and robotics, and human-centric approaches that would usher in a new paradigm for smart manufacturing. This is an evolution at the core of middleware architecture as an enabling force for seamless integration, interoperability, and real-time decision making across complex industrial ecosystems. This paper discusses the design and development of scalable and secure middleware architectures in Industry 5.0 smart manufacturing. This paper addresses heterogeneity in the integration of devices, data silos, latency-sensitive operations, and increasingly sophisticated cyber threats that make manufacturing critical. This research introduces a multi-layered middleware approach to adaptive workload management and real-time analytics with modular microservices, distributed edge computing, and advanced machine learning techniques. State-of-the-art security is adopted to protect the most critical operations with blockchain-based data validation, Zero Trusted principles, and privacy-preserving data sharing. The main contributions of this work are a novel middleware framework that enables interoperability between legacy systems and modern IoT devices, supports human-machine collaboration, and ensures scalability for varying production demands. The paper furtherly provides a comprehensive evaluation of the proposed architecture through simulation and real-world case studies, demonstrating its effectiveness in enhancing operational efficiency, reducing downtime, and fortifying system security. Findings of this study research are actionable and provide practical frameworks for the deployment of scalable and secure middleware solutions in order to address technical and organizational challenges of Industry 5.0.

Keywords: Middleware architecture, Industry 5.0, smart manufacturing, IoT, scalability, and cyber security.

1. Introduction

In today's fast-paced industrial landscape, adopting advanced technologies is crucial for businesses aiming to enhance their operational efficiency and productivity while boosting their competitiveness. The Industrial Internet of Things (IIoT) has paved the way for the creation of smart automation modules that can transform industrial processes in remarkable ways. With this capability, organizations can develop intelligent systems that seamlessly connect nearly all of their devices, sensors, and machines, facilitating instant data exchange, analytics, and automation. The IIoT framework [1] for constructing smart automation modules involves integrating hardware, software, and communication technologies into a robust and interconnected ecosystem. These modules improve process automation, monitor equipment performance, optimize resource use, and enable predictive maintenance. They can collect vast amounts of data from various sources, offering valuable insights for informed

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decision-making and process optimization. The smart automation modules are designed for real-time monitoring and control of industrial operations. They employ sensors and actuators to collect data on temperatures, pressures, humidity levels, and energy consumption parameters, ensuring optimal performance through precise control and adjustments. This results in efficient operations, reduced downtime, and high-quality products. Moreover, the IIoT framework connects different components of the manufacturing process, allowing for seamless data sharing and collaboration throughout the entire supply chain. This connectivity promotes effective planning of production, inventory management, and logistics optimization. For example, manufacturers gain real-time visibility into their operations, enabling timely decision-making and swift responses to changes in market demand [2].

Smart automation modules, developed with the help of IIoT architecture, contribute to improved safety in the industrial environment.By embedding sensors and intelligent algorithms in these modules, they can detect anomalies, predict hazards, and trigger preventive measures to make the work environment safer for employees and minimize accidents.

2. Proposed Secured Framework for Implementation of IIOT SmartAutomation

In this research, we have chosen one of the brick manufacturing processes in which various sensors have been installed for monitoring and control of the process. The proposed security framework for IIOT smart automation does not only consist of smart sensor features but also includes security features by standard procedures and frameworks. As illustrated in Figure1, we have considered the following step in which various sensors are placed:

1.Operator

The smart automation system is used with operators. These systems are built to support and enhance the performance of human operators, which would make them perform a particular task more efficiently and effectively. Operators interact with the smart automation system by intuitive user interfaces, where they monitor processes, access real-time data, and control equipment remotely. At this point, the operator will be monitoring the real-time data from various sensors and RTUs to control and analyze the process flow.

2. Storage of Plastic Waste. Another significant consideration in a plastic brick manufacturing plant is that of the storage of plastic waste. As environmental consciousness continues to grow, plastics production processes must ensure that appropriate handling and management of generated plastic waste are undertaken, which is to be suitably stored in the appropriate area of the plant before segregation, containment, and proper disposal. This encompasses the use of strong storage bins or containers specifically for plastic waste. The containers should be durable, leak-proof, and easily accessible to workers to dispose of plastic waste materials. The plant must have proper guidelines and procedures to segregate and store various kinds of plastic waste such that the recyclable as well as non-recyclable plastics are segregated properly. Also, the waste storage area should be inspected periodically and maintained properly to prevent possible environmental hazards [3]. Proper plastic waste

storage management in the plastic brick manufacturing plant would reduce the adverse environmental effects of plastic waste and increase sustainability in the plastic industry.

3. Plastics Shredder with Vibration Sensor

The incorporation of a vibration sensor in plastics shredder is an innovation that changes the efficiency of shredding and helps enhance security.

The vibration sensor monitors the vibrations that the shredder produces when it is working. By analyzing these vibrations, it can detect abnormalities or irregularities in the shredding process. It thus gives real-time monitoring of the machinery allowing early intervention and preventive maintenance for least chances of equipment breakdown. This might cause red alerts by a vibration sensor, in case there was extreme shredder vibration, because it senses some forms of misalignment or even blockage alerting operators about some possible corrective action that will be needed. General performances are enhanced, including service lives, of the shredder and helps the operator, avoiding all dangers through any possible accidents. The data acquired by the vibration sensor can be analyzed and used for predictive maintenance, thus optimizing the operational efficiency of the plastics shredder. The plastics shredder becomes a smart and reliable tool in the plastic recycling process with the integration of a vibration sensor, offering real-time monitoring and enhancing the productivity and safety of the shredding operation

4. Conveyer belt

Integration of sensors on a conveyor belt at a plastic brick manufacturing plant provides several benefits in its production process.

Sensors are implemented along the conveyor belt so that it picks up and tracks all parameters. For example, proximity sensors can recognize the emergence of plastic bricks and ensure smooth movement of the conveyor belt so as not to have jams or blockages, which then leads to overall efficiency and productivity in the manufacturing plant [4]. Sensors can also be used to weigh or measure the dimensions of the plastic bricks for consistency and quality control along the production line. Since the sensor-equipped conveyor belt collects real-time data, it is possible to continuously monitor the process and intervene promptly in case of deviations or abnormalities. This will improve the accuracy and precision of the manufacturing process and produce high-quality plastic bricks. Furthermore, sensor data may be integrated into a central control system that enables the operator to monitor the production status and make informed decisions on optimization and improvement. Generally speaking, with sensors in a conveyor belt system, automation increases efficiency and quality control improves while the outcome is smooth operation and continuous output.

5. Mixers

a) The plastic mixer trommel is a crucial component of a plastic brick factory. This specialized machinery is designed to mix plastic materials effectively. It features a rotating drum equipped with perforations or screens that facilitate the separation and blending of plastic particles. As the drum rotates, the plastic materials are agitated, resulting in a uniform mixture. This process is essential for achieving the desired composition and consistency in the plastic bricks. Moreover, the trommel helps eliminate impurities or contaminants from the plastic materials, ensuring the production of high-quality bricks. Additionally, sensors or monitoring devices can be integrated into the trommel to track temperature, moisture content, and mixing time, enhancing the accuracy of the mixing process. The plastic mixer trommel significantly boosts the efficiency, productivity, and quality of plastic brick production, making it an indispensable part of the production line.

b) Sand Mixer with Trommel: Designed specifically for mixing sand with other additives for uniform well-blended mixture, a mixer or agitator is often utilized. The sand mixer will consist of a big drum or container and blades inside in rotation. As the drum turns, agitating the sand with other materials is quite common where by them mix up well and well-distributed. The trommel separates and screens particles to obtain the desired size and quality required for brick making, in the sense that it is a part of the integrated sand mixer. This ensures uniformity and durability in the bricks that will be produced by the use of quality-consistent sand during plastic brick production. It has sensors and controls on factors like temperature of the sand, moisture content, and time for mixing so as to achieve total control over and optimization of the mixing process. The effective mixing and sieving ability of the sand mixer with trommel enhances the overall efficiency and quality of the plastic brick production process, ensuring reliable and high-performance bricks [6].

6. Sand Reserve

It is used as a reserve for storing the amount of sand needed in brick manufacturing. The quantity of sand is one of the raw materials needed for brick production. The sand storage area is planned in such a way that the sand is well organized and protected from external factors such as moisture and contamination. Storage bins or silos are usually used in this area, which can store a large quantity of sand. The storage area is planned strategically near the production line so that sand can be transported easily to the mixing process. Proper sand storage management involves constant monitoring and replenishment to ensure that there is an uninterrupted supply of sand for the manufacturing process [7]. To achieve this, proper utilization of a well-organized and controlled system of storage of sand helps optimize the production efficiency by maintaining the quality and consistency of the sand used in plastic brick manufacturing.

7. Upper Part of Smart Vessel with Capacitive Sensor

The capacitive sensor is incorporated into the vessel's design and located within it in a position that would allow for some optical monitoring of the liquid or material level inside. It employs the phenomenon of capacitance by detecting alterations in a dielectric constant associated with the presence or non-presence of the measurand. Real-time information provided by the capacitive sensor can thus be used for real-time control of filling or dispensing processes by measuring accurately the liquid or material level. It makes it possible to have the contents in the vessel fully managed and controlled, reducing resources usage as well as avoiding unnecessary wastage. The capacitive sensor of the smart vessel in the top side increases the automation with higher efficiency in the manufacturing of plastic bricks, thus resulting in greater productivity and cost-effectiveness.

8. Sliding plate with Load Cell Sensor & Pneumatic Cylinder with solenoid Valve:

This mechanism is used to enable controlled movement along with precise positioning of the material being used in the production process. The load cell sensor on the sliding plate helps in measuring the weight or force exerted on the plate. This can then give real-time feedback on the material's load to maintain consistency and optimize the manufacturing process. A pneumatic cylinder, controlled by a solenoid valve, allows smooth movements of the sliding plate with wide control provisions. It works on the principal of compressed air, making positioning of the plate quite specific and variable. The system provided by load cell sensor with integration of a pneumatic cylinder having a solenoid valve allows material handling very accurately to limit errors and waste. Thus this automation element improves the overall efficiency and productivity of the plastic brick manufacturing plant and contributes towards consistently high output quality.

9. Screw Extruder with Capacitive Sensor

This is an apparatus that melts and extrudes plastic material into a desired brick shape. The screw extruder has a rotating screw contained in a cylindrical chamber. As plastic material enters the chamber, it is subjected to pressure and heat by the screw to melt the plastic into molten plastic. The capacitive sensor is actually integrated into the extruder, continuously measuring the amount and consistency of molten plastic. The change in capacitance is measured due to this, which will be the dielectric constant of plastic, thus giving instantaneous feedback in terms of the material itself. This would be indispensable for maintaining ideal extrusion conditions and also for uniform product quality. The screw extruder along with capacitive sensor makes available the precise flow rate of plastics, temperature, and pressure in order to produce homogeneous high-quality plastic bricks. This automation component makes manufacturing processes more efficient by lessening material waste and making the production process more efficient.

10. Access Point Control

Access Point Control is an aspect that is key in the process of smart automation, primarily in a manufacturing setting. It basically refers to how access points are controlled or managed in a network infrastructure. Access points are the pathways through which the devices gain an entry point and communicate with the network. Access Point Control, therefore, allows administrators to regulate and monitor access to the network so that only authorized devices and users can enter. This is helpful in the maintenance of network security as well as preventing unauthorized entry and the protection of sensitive data. Access point control can enable the administrator to define some form of authentication, such as a password or digital certificate that would identify a device or user for access purposes [8]. Access point control can further provide a mechanism to allow data transmitted across the network to be encrypted. It also includes logging and monitoring access attempts for analysis of network utilization as well as possible security violation. By effectively managing access points, organizations can establish a robust and secure network infrastructure for their smart automation systems, safeguarding critical information and maintaining the integrity of their operations. At this level the user is enabled to access the points of control for ensuring the proper commissioning and working of devices and sensors integrated with to the various process described in the above sub sections.

The user can monitor all the process points on his / her mobile or tablet or any other human interacting devices. Fig 1 presents the proposed architecture and implementation of IIOT Smart Manufacturing in the plastic brick manufacturing industry [9]. The architecture presents the integration of several components and processes that achieve smart automation. Based on this architecture, Fig 2 illustrates the smart automation model designed above in the chapter's previous sections. The first phase of the model is the process analysis, where an existing system is studied through and through to identify its deficiencies and limitations.

This analysis acts as the basis for strategy building towards overcoming these deficiencies. The required sensors are determined through meticulous planning, designing, and analysis that will play a crucial part in increasing the degree of automation. With the positions and types of sensors established, the hardware components are designed to accommodate the proposed sensors in the system. This hardware design phase incorporates the utilization of Arduino modules and other circuitry components that are essentially needed to make the system work efficiently. The integrated sensor data is extremely useful for the effective control of production. Leverage data collected from sensors, the system monitors and controls the process of production. Through monitoring and control in real-time, fast decisions are made at optimal efficiency and productivity. In general, the proposed model is a holistic approach to smart automation in the plastic brick manufacturing industry[10]. Using advanced sensor technologies, hardware design, and real-time data analysis, the model promises to revolutionize the process of manufacturing, with increased accuracy, control, and productivity. Fig 2 provides an outline of the proposed methodology in implementing smart automation into any manufacturing industry. In general, the analysis is based on a detailed understanding of the process: from raw materials through finished goods production chain. This analysis will find out where there is a scope for automation to make maximum impact.After the process analysis, the current techniques and practices are critically examined for their drawbacks and limitations.

These identified shortcomings form valuable insights in planning and designing a more efficient and optimized process flow. The idea is to address these drawbacks by integrating smart automation technologies. Based on the analysis and planning, the next step would be to determine the best locations for sensor installations to ensure that the sensors are placed strategically to capture relevant data and enable effective automation. The sensors are crucial in gathering real-time data and providing valuable insights for the control and optimization of the process. Once the locations and categories of sensors are identified, the hardware systems are designed and implemented into the existing manufacturing setup. This would involve the deployment of different components and technologies, including Arduino modules and other necessary circuitry, to facilitate the integration of the smart automation system.

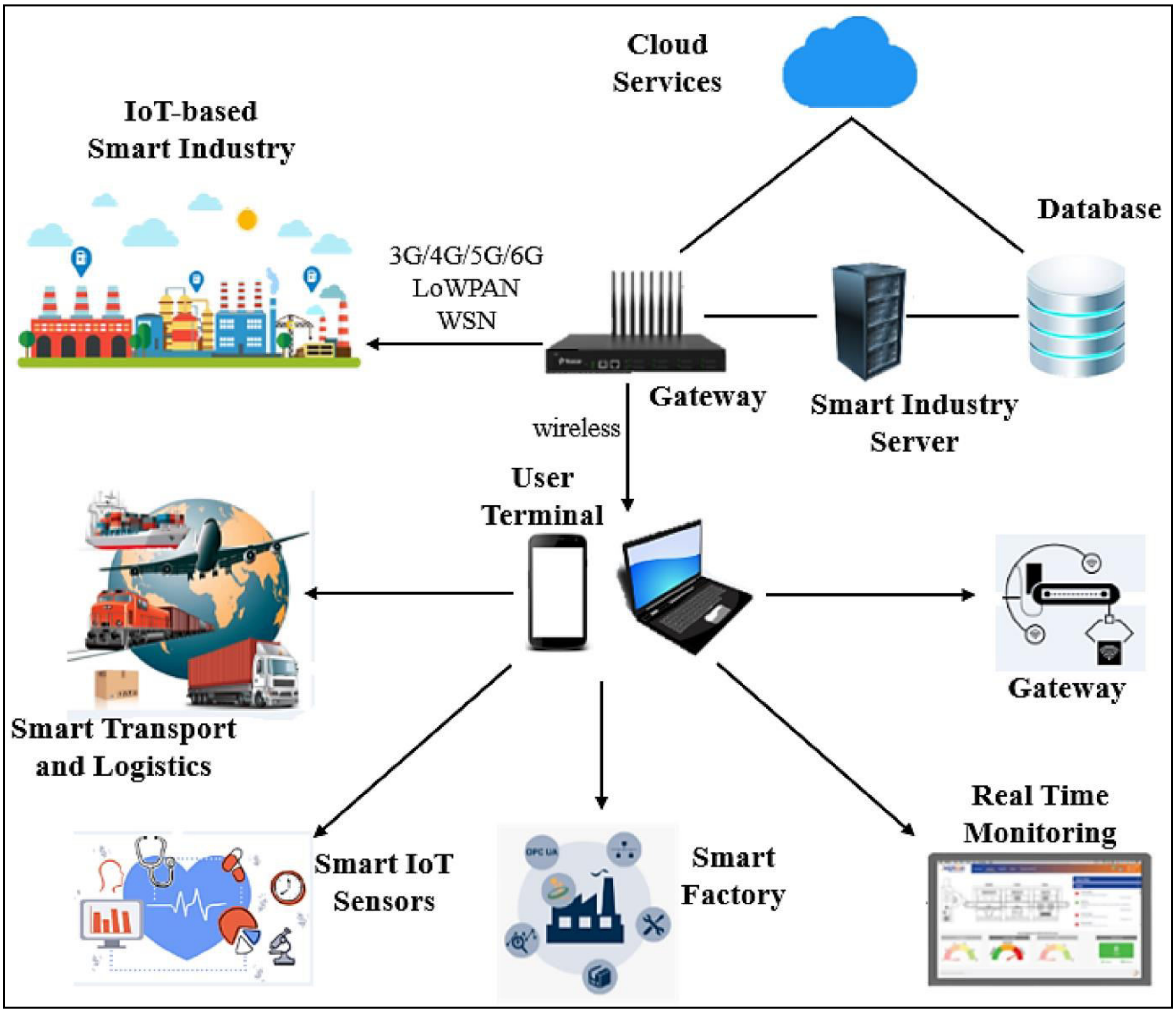

Figure 1: Proposed architecture of IIOT in the Plastic Manufacturing Process

Fig 3 provides a more detailed view of the installations by offering a comprehensive depiction of the setup process. It specifically points out the components and connections involved in implementing smart automation within the manufacturing environment. Following this proposed methodology will enhance the operational efficiency, productivity, and overall performance of manufacturing industries by harnessing the power of smart automation.

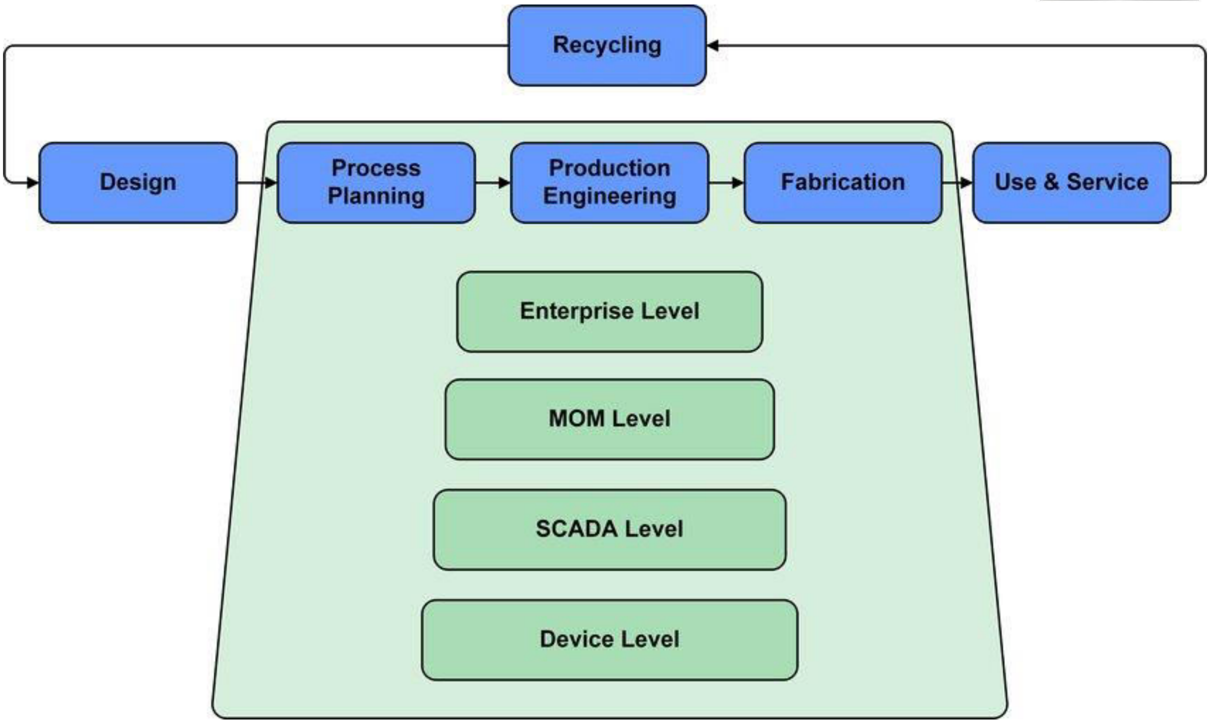

Figure 2: Steps to Implement Smart Automation for Manufacturing Process

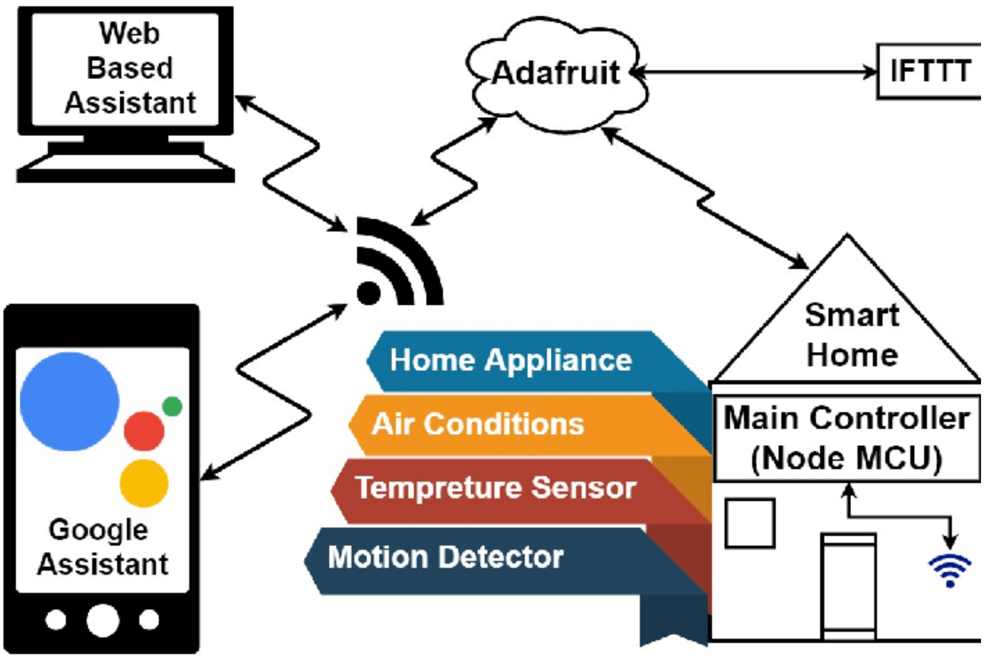

Figure 3: Detailed View of Smart Automation Implementation

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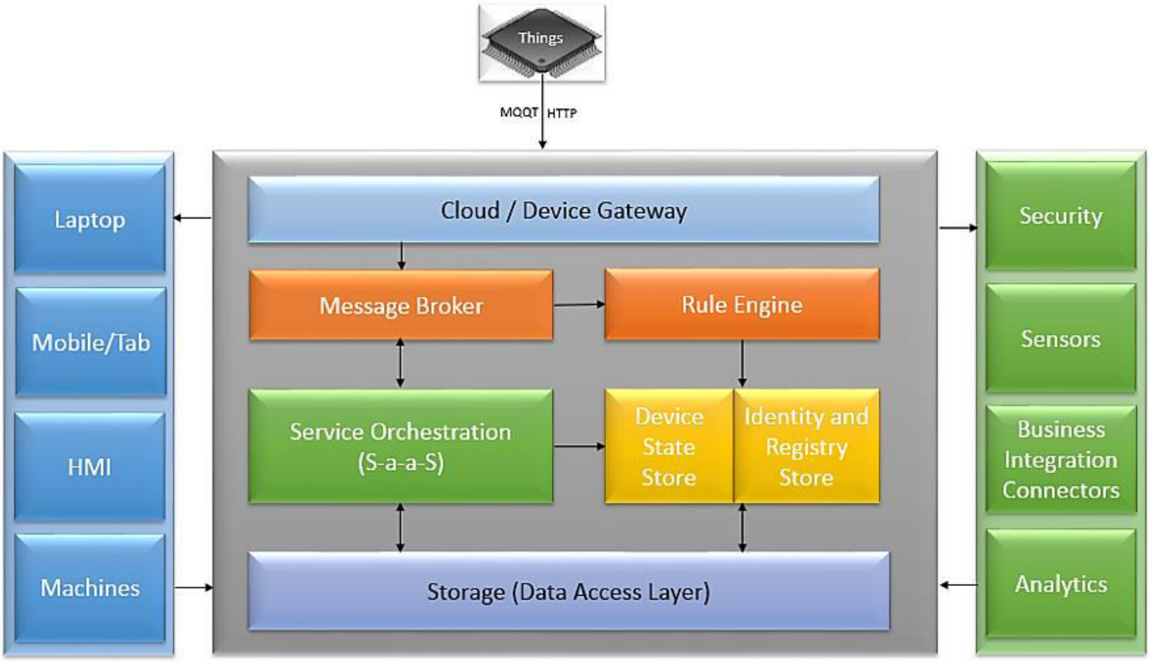

Figure 4: Conceptual view of IIOT Architecture

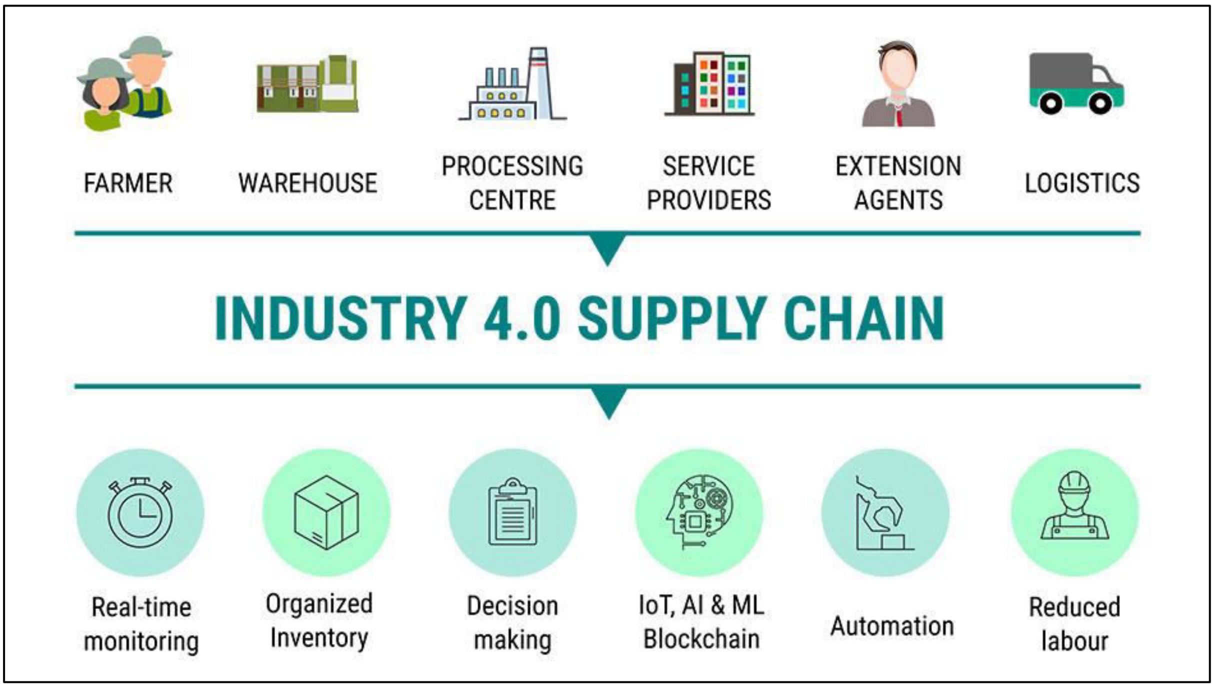

Figure 5: Implementation of Collaborative Manufacturing in IIOT supply chain

Fig 4 and 5 detail the implementation of the IIOT Environment for individual and collaborative manufacturing. The collaborative manufacturing setup in the environment of the IIoT represents an innovation in manufacturing orchestration. This system emphasizes integration and coordinating devices, systems, and actors networked together so as to facilitate efficient cooperation along with data exchange[11]. Utilizing IIoT technologies such as sensors, analytics of data, and computing via clouds, collaborative manufacturing will achieve the real-time data exchange and the intelligent decision making resource optimality.

This enables collaboration among various entities in a collaborative manufacturing environment with machines, robots, and human beings but even external partners to thereby enhance flexibility, agility, and responsiveness.There are dynamic adjustments in production processes to meet changing demands and optimise resource allocation, owing to the shared data and insights generated from interconnected devices and systems, which facilitate better visibility and transparency across the value chain in the manufacturing process.

Additionally, collaborative manufacturing in the context of the IIoT inspires cooperative and intelligent decision-making. By employing data analytics, manufacturers may be able to learn important insights about what happens on the shop floor, including supply chain dynamic patterns, customer preferences [12]. This allows informed decisions to be made, it also makes predictive maintenance more effective, thereby enhancing quality.

Innovation and continuous improvement is a vital result of using collaborative manufacturing in the IIoT scenario. The collection and instantaneous analysis of massive data sources would allow manufacturers to pin out the spots where to improve, determine the actual bottlenecks, and adopt proactive measures that maximize efficiency and quality. It keeps people engaged in an intrinsic pursuit of innovation and collaboration-the hallmark of the iterative characteristics of collaborative manufacturing.

3. Sensors and Applications Design and Integration In plastic brick smart manufacturing, sensors monitoring and controlling several variables of a production process. Sensors do play a major role for real-time data collection with automation and the optimization of the manufacturing processes. This section discusses several common ones used in plastic brick manufacturing in smart manufacturing.

1. Temperature Sensors: Temperature sensors, which can be in the form of thermocouples or resistance temperature detectors (RTDs), are used to measure the temperature of various components in the manufacturing process. They help maintain optimal temperatures for melting, mixing, and curing plastic materials. This sensor is installed at the extruder to monitor the temperature raise, if the temperature exceeds the threshold value set by the user then it will send a warning signal to the operator for further necessary action.

2. Pressure Sensors: Pressure sensors are used to measure pressure in different stages of manufacture. It ensures that a required amount of pressure occurs while plastic material is in process of extrusion or moulding or compression. For consistency of quality and zero allowance of deviation or flaws it does all this. Hence the above mentioned pressure sensor finds an application at mixer level by measuring the actual pressure released.

3. Proximity Sensors: Proximity sensors, including inductive or capacitive sensors, are used for detecting the presence or absence of objects or materials. These sensors help in the automation of material handling, position monitoring of components, and proper alignment of molds or dies.

4. Level Sensors Level sensors are used to determine the liquid or solid materials in a container or a tank. In plastic brick production, they can be applied for monitoring the levels

of raw materials, such as sand or additives, in hoppers or storage tanks so that they are available constantly in the process.

5. Flow Sensors: Flow sensors measure the flow rate of liquids or gases in pipes or ducts. They could be used to monitor materials being mixed or cooled for plastic brick production, hence ensuring that the flow rates will be accurate and consistent.

6. Vibration Sensors: Vibration sensors are used for detecting and monitoring the vibrations or oscillations within machines or equipment. It helps one identify abnormal vibrations, which indicate that equipment failure or malfunction is imminent; thus, it can be serviced beforehand and avoided from going out of commission, as presented in Figure 6. These are some of the sensors used in smart manufacturing in the plastic brick industry. The type of sensors used will depend on the manufacturing requirements, process complexity, and the level of automation at the manufacturing facility.

Figure 6: In vibration and tachometric sensors, the shredder shaft performance monitoring is implemented. Specifically, these sensors measure and analyze real-time vibrations and speed variation. These sensors are always monitoring the shaft at all times and are aware of the abnormal behavior or sudden jerks resulting from the shredding and breaking of large plastic materials.

Figure 6: Location of ACC 10244 Vibrational sensor and tachometric sensors

All these vibrational data are sent flawlessly across the network to the operator for interpretation and even direct action if possible. The real-time feed provides feedback that enables the operator to act promptly to the situation that may be present. Such ensures that the shredder will be running smoothly with less possibility of damage or malfunctions. In

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summary, the deployment of vibration and tachometric sensors offers considerable insight into the shredder's operating condition, thus improving performance and reliability in the manufacture of plastic bricks 13.

Figure 7: Smart Monitoring at operator end

The smart monitoring at the operator's end using a tablet, as depicted in Fig 7, is an innovative approach that brings convenience and efficiency to the manufacturing process. By equipping the operators with tablets, the operators get access to real-time data and monitoring capability right at their fingertips. Tablets are integrated with smart applications and software that allow the operators to remotely monitor and control various aspects of manufacturing operations. This comprises live data streaming from sensors, monitoring of the production, setting adjustments, and even alerts or notifications. Annexure A contains the comprehensive codes. With the presence of smart monitoring on the tablet, operators are not anymore required to stay present on the production floor. They can easily take the tablet with them so that they can monitor a number of processes at once and still be in contact with manufacturing operations anywhere within the plant[14]. The natural user interface of the applications on the tablets makes the monitoring easy and simple and allows operators to quickly move across various screens and find their desired information.

In addition, smart monitoring on tablets improves decision-making power. Operators can analyze data in real time and their performance metrics to identify the anomalies or issues that are likely to occur during manufacturing. With instant access to critical information, operators are able to take timely corrective actions, optimize production parameters, and ensure smooth operations [15]. They can share data and insights with other team members to improve better communication and coordination.

Node-RED is a graphical user interface that is used in the development of IoT applications through visual programming. Node-RED will change the brick industry if it facilitates the use and management of IoT technology. The adoption of Node-RED for IoT purposes within the brick sector involves some important aspects such as: 1. Sensor Integration:

Node-RED makes it easy to include different sensors used in the brick manufacturing process. It allows easy integration with sensors that measure temperature, humidity, pressure, and other relevant parameters in the manufacturing environment.

2. Data Processing and Analysis:

Node-RED's graphical programming tools allow real-time processing and analysis of sensor data. Maintaining the right conditions during production is crucial in the brick industry to maintain product quality.

3. Workflow Automation:

Node-RED makes it possible to automate the workflow of brick manufacturing. It can be used to create sensible sequences of events that cause the action in response to specific events, thereby streamlining and optimizing the cycle of production.

4. Remote Monitoring and Control

Node-RED allows brick manufacturing business people to monitor and control the different aspects of production at a distance. This is particularly useful when several plants have to be managed or there is a need for urgent changes to maintain high efficiency.

5. Alerts & Notifications

The system allows alert/notifications to be configured and set up. Node-RED can sense a shift in some of the chosen metrics from the desired patterns. In this instance, it can automatically create a notification for the operator/management to take necessary correcting actions immediately.

6. Interoperability with other systems:

Node-RED is able to interact with other enterprise systems, such as ERP (Enterprise Resource Planning) or MES (Manufacturing Execution System), seamlessly. This ensures that different parts of the business can communicate well.

7. Custom Dashboards:

The operators are able to create their own dashboards using Node-RED, which will provide a graphical view of key metrics and real-time information. This allows for quicker decision-making and performance analysis.

8. Scalability and Flexibility:

Node-RED has scaling and adaptability, thus suitable for small, medium, and large-sized brick manufacturing processes. It accommodates the growing demands of the industry and can be adapted to the changes of IoT technology.

4. Secured Framework

In the smart manufacturing arena, connection to sensors and access to information is of paramount importance for each sensor. Since each sensor provides valuable information about each aspect of the manufacturing process, manufacturers can gather data and provide detailed analysis to derive meaningful insights that can be used for informed decision-making.

However, in order to secure the data and then the whole system, it's important to have a highly developed network infrastructure. To answer the problem, one network configuration alone is implemented wherein all of the sensors are connected. Therefore, the number of the access points is reduced. By this, vulnerabilities are decreased with easier implementation of tight security measures. Having a single gateway through which to access the network can help manufacturers consolidate their efforts to improve security and implementThis will create a more secure environment within the network and support proper data governance. It makes the management and monitoring of the data flow from the sensors to the central network structure efficient in creating integrity, confidentiality, and availability to ensure that the collected data is reliable and protected. In terms of future improvement, more security features can be added to make the network even more secure. Setting up a firewall may be an added layer of security because it monitors and controls the incoming and outgoing network traffic.

IPS and IDS can be deployed to detect and prevent unauthorized access or malicious activities within the network. These advanced security measures strengthen the overall security posture, which safeguards the sensitive data and the integrity of the manufacturing processes.

Here are some points to ponder for analyzing the security framework for the smart automation with IIOT:

a. Advanced Access Control:

Smart IIoT automation also facilitates secure access control mechanisms in brick manufacturing facilities. In this regard, biometric authentication, smart cards, or mobile devices may be used to control stringent access to sensitive areas and equipment. This prevents unauthorized people from playing with machinery, altering production settings, or compromising the manufacturing process. b. Real-time monitoring and intrusion detection

IIoT-enabled sensors and surveillance systems allow for real-time monitoring with intrusion detection capabilities. Analysis of data collected from video cameras, motion sensors, network logs, etc., may detect suspicious activity or a potential security breach, which can be responded to immediately. It helps manufacturers reduce the security risks that might compromise the integrity of the manufacturing environment or interrupt operations.

c. Data Encryption and Secure Communication:

Smart IIoT automation ensures the encryption of data transmitted between devices and systems. By implementing secure communication protocols, such as Transport Layer Security (TLS) or Secure Shell (SSH), the confidentiality and integrity of sensitive data, including production plans, product specifications, and customer information, are safeguarded. This protects against unauthorized interception or manipulation of data, reducing the risk of data breaches and intellectual property theft.

d. Cyber Threat Detection and Prevention:

It is given in smart IIoT automation to identify and prevent cyber threats in advance by providing advanced measures of cyber security. Systems and network traffic monitoring allow anomaly detection algorithms and firewalls along with intrusion detection systems to determine abnormal behavior of networks or suspected cyber attacks. Also, through system log and network traffic monitoring, signs of potential unauthorized access attempts, malware infections, or data exfiltration can be recognized. With such emerging threats being detected and mitigated promptly, brick manufacturers can proactively protect their digital infrastructure and avoid interruptions or sensitive information compromise through cyber incidents.

e.Security Incident Response and Recovery:

Smart IIoT automation helps to respond and recover from a security breach or system disruption quickly. For example, manufacturers can include incident response plans and backup and recovery procedures to contain the effects of security breaches and quickly restore operations. Automated backup mechanisms and redundant systems ensure data resilience and facilitate the recovery process, reducing downtime and potential financial losses associated with security breaches. The implementation of the proposed measures has been in the establishment of a highly secure and controlled environment. The area has been locked off, thus strictly limiting the persons who have accessed it. This has assured physical security on the premises and halted unauthorized access.

With a new cuttingedge access point installed, there is now tremendous improvement in the network. This access point serves as a centralized hub from where devices are easily connected into it and become available on the network seamlessly. All machines that utilize sensors are already linked to this access point using the Ethernet module, making possible effective data transfer as well as communication between them in enhancing general system performance.

5. Evaluation and Performance Indices

To evaluate the performance of the proposed system for smart manufacturing of plastic bricks certain indices has been considered. These evaluating parameters are not limited but have covered all the extensive utilities of the smart automation using IIOT. They are shown in Figure 8.

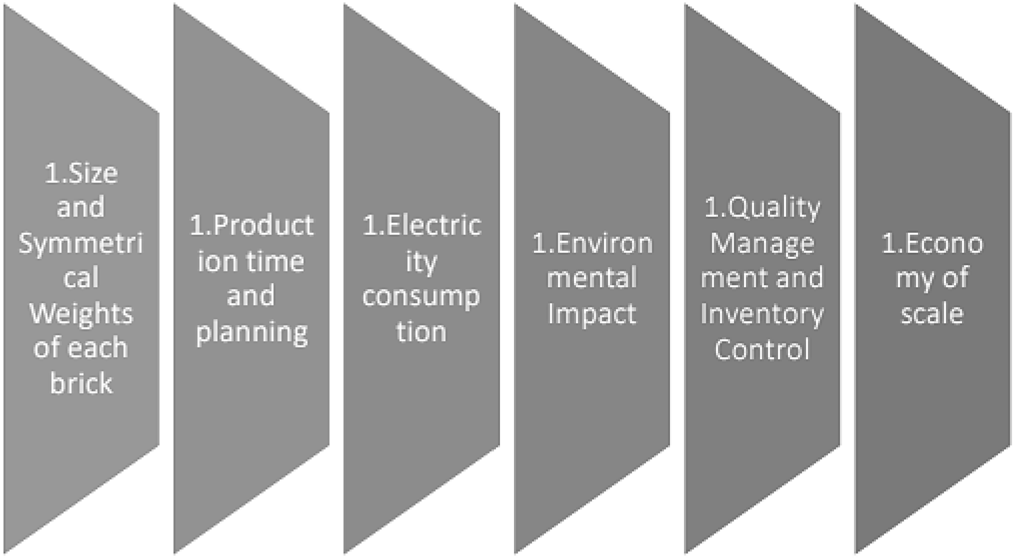

Figure 8: Evaluation and performance Indices

Moreover, these performance indices have been widely discussed in the context of various total quality management criteria. These criteria include a vast array of aspects such as real-time data monitoring, predictive maintenance, supply chain optimization, process optimization and control, energy monitoring, energy demand management, energy optimization, waste reduction, emission control, water conservation, environmental monitoring, quality control, statistical analysis, traceability, raw material demand forecasting, automated just-in-time delivery, production planning, rapid changeovers and setup times, scalability, and optimization.

Apart from these aspects, there are comprehensive security frameworks that have ensured the system integrity and confidentiality. In this regard, some intrinsic performance indices are considered. These indices include enhanced access control measures to restrict unauthorized access, intrusion detection mechanisms to identify and respond to potential security breaches, secure communication protocols to protect data transmission, data encryption techniques to safeguard sensitive information, cyber threat detection and prevention mechanisms to mitigate the risks associated with cyber-attacks, and response and recovery strategies to minimize the impact of security incidents and ensure business continuity.

The integration of such performance indices along with security measures plays an important role in smart automation and the applications of IIOT, ensuring the smooth functioning of such a system. Organizations can maintain their position within the competition and achieve the set quality management objectives as well. Since these performance indices contribute toward the realization of a lot of issues related to operation, environmental, and security, there is scope for effectiveness in the overall process of sustainability of smart manufacturing.

5.1 Economy of Scope

The smart IIoT (Industrial Internet of Things) automation has several advantages on the economy of scope in the brick manufacturing industry. Economy of scope relates to the cost advantages and efficiencies gained by producing a broader variety of products within the same production system. Here are ways in which smart IIoT automation improves the economy of scope in the brick manufacturing industry:

a. Flexible Production Capabilities:

Smart IIoT automation allows brick manufacturers to be flexible in their production capability, thereby enabling them to make several types of bricks of varying sizes and designs without major reconfiguration or retooling. Connected machines and systems can be programmed to adapt to varied product specifications, thus meeting diversified customer demands and tapping new market opportunities.

Rapid Changeovers and Setup Times

IIoT-enabled automation of changeovers and setup times in brick manufacturing. Digital control systems, automated adjustments, and preconfigured settings allow for fast changes between different product configurations. Downtime is reduced, production efficiency is increased, and manufacturers can easily offer more variety without delays or disruptions.

c. Scalability and Customization:

IIoT automation offers scalability and customization capabilities in brick production. Through digital connectivity and data-driven processes, manufacturers can scale up or down their production depending on market demand. In addition, smart automation offers customized production by taking into account the individual preference and specifications of the customers. This makes it possible to provide custom brick products without compromising on efficiency and cost, which increases the overall economy of scope.

5.2 Quality Management And Inventory Control Smart

IIoT (Industrial Internet of Things) automation has greatly improved quality management and inventory management and control in the brick manufacturing industry. The use of advanced technologies and data-driven processes helps manufacturers improve their overall quality of products and streamline inventory management. Here are a few ways smart IIoT automation improves quality management and inventory management and control in the brick manufacturing industry.

a. Quality Control:

Intelligent IIoT automation allows manufacturers real-time measurement capabilities with regard to parameters, ensuring quality as in bricks' manufacturing. Information retrieved will range from temperatures to moistures and pressures; consequently, possible deviations may point the affected aspect of a production which influences the outcome on products of final nature. Having accessed current information, this assures current appropriate corrective measure input during and after every shift.

d. Statistics Processing:

IIoT-based systems can analyze quality data gathered from multiple sources using statistical methods. Predictive analytics and machine learning algorithms can be applied in this regard to identify patterns and correlations that may indicate a possible quality issue before it arises. This approach prevents defects and lowers rework while increasing overall product quality.

c. Traceability and Recall Management:

Smart IIoT automation allows for the accurate tracking and traceability of bricks at each stage of the production process. Each brick can be assigned an identifier, and manufacturers will be able to trace its origin, production details, and all quality-related information. In the case of a quality issue or recall, manufacturers can immediately identify affected products and undertake necessary actions to minimize impact on customer satisfaction and brand reputation.

5.3 Electricity Saving

With this smart IIoT automation, the electric consumption is increased manifold in the industry, providing improved energy efficiency and significant savings. Smart IIoT automation optimizes the usage of energy, reduces waste, and generally increases sustainability of energy with the help of advanced technology and real-time data analysis as presented in table 1.

Table 1: Electricity Consumption Of Various Brick Production Techniques

Process	Clay Brick	Calcium Silicate Brick	Concrete Brick	Plastic Brick
Raw material extraction	0.169	0.119	0.106	0.0848
Raw material transportation	0.0095	1.724	0.0597	0.04776
Drying / Firing	8.57	0	0	0
Preparation / Forming	6.501	-	1.254	1.0032
Conveyance in plant	0.0945	0.179	2.671	2.1368
Brick Processing	15.15	2.754	1.465	1.172
Natural Gas	3.671	3.551	1.819	1.4552
Diesel Road	0.153	0.819	0.714	0.5712
Electricity	2.751	0.431	0.3645	0.2912
Total	**37.069**	**9.577**	**8.4532**	**6.76216**

Energy Demand and Consumption: Smart IIoT automation ensures the real-time monitoring and analysis of energy consumption in brick manufacturing facilities. Manufacturers can use smart meters and sensors integrated along the various stages of the production process to collect real-time data regarding electricity usage in kiln operation, material handling, and performance of equipment. Then, by analyzing such data, they could identify areas where energy usage is intensive, detect inefficiency, and make proper decisions toward optimizing energy usage.

Energy consumption not only contributes to environmental sustainability but also yields economic advantages by significantly lowering electricity expenses. This academic analysis underscores the importance of adopting innovative strategies to enhance energy efficiency and cost-effectiveness in industrial operations. In Fig 9, the academic analysis presents the data on hourly energy consumption specifically for the brick drying process. The findings bring about a significant impact with respect to the incorporation of smart automation in the production process; energy consumption reduces about 25%. The explanation can be attributed to improved scheduling and optimization of time periods, together with batches in terms of manufacturing, hence efficiently utilizing more energy.

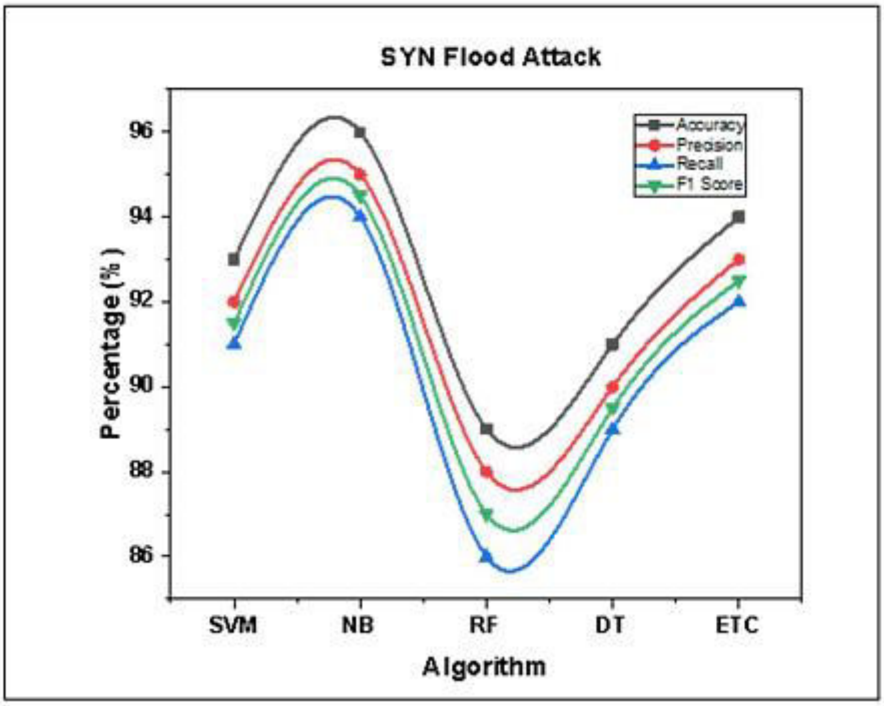

Figure 9: SYN Flood Attack Analysis

Significantly, this energy saving has translated into concrete monetary savings. The electricity bills have reduced by a significant 20.77% and stand at Rs. 8.85 per kWh in Rajasthan. This should be taken in the context that these numbers do not include the surcharges and levies imposed by the Rajasthan government on top of the per unit energy consumption. Considering all these factors, the total cost saving would be much higher. This outcome shows that the adoption of smart automation technologies in brick manufacturing will bring in several positive results.

6. Conclusion

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