

Multichannel Data Acquisition and Monitoring System Utilizing Modbus Protocol with IIoT Automation

Dr. Vijaya N. Aher¹, Dr. Manoj Bhalerao², Dr. Rahul Pol³, Dr. Vidya More⁴, Dr. Pratibha P. Chavan⁵, Dr. Ajay K. Talele⁶

¹Assistant Professor, Department of Electronics and Telecommunication, Vishwakarma Institute of Technology, Pune, Maharashtra, India. vijaya.aher@vit.edu

²Associate Professor, Department of Electronics and Telecommunication, PVG's College of Engineering, Nashik, Maharashtra, India. hod_etc@pvgcoenashik.org

³Assistant Professor, Department of Electronics and Telecommunication, Vishwakarma Institute of Information Technology, Pune, Maharashtra, India. rahul.pol@viit.ac.in

⁴Assistant Professor, Department of Electronics and Telecommunication, COEP Technological University, Pune, Maharashtra, India. vnm.extc@coeptech.ac.in

⁵Assistant Professor, Department of Electronics and Telecommunication, Trinity College of Engineering and Research Pune, Maharashtra, India. pratibhachavan.tcoer@kjei.edu.in

⁶Assistant Professor, Department of Electronics and Telecommunication, Vishwakarma Institute of Technology, Pune, Maharashtra, India. ajay.talele@vit.edu

Article History:

Received: 02-08-2024

Revised: 22-09-2024

Accepted: 05-10-2024

Abstract:

This paper introduces a multi-channel data acquisition and monitoring system that integrates Modbus communication protocol and IIoT automation to improve business. The system is designed to capture and monitor multiple parameter data simultaneously, providing accurate and fast measurements of variables such as temperature, humidity, and pressure in various applications. The system uses the widely used Modbus protocol, known for its reliability in industrial automation, to ensure seamless communication between interconnected devices and thus promote interoperability in more diverse aspects of the network environment. Working with IIoT automation, the system not only facilitates data collection, but also helps increase intelligence to focus on business efficiency. Its multi-channel architecture supports data obtained from eight different channels, making it adaptable to complex business processes or research operations that require high precision and scalability. In addition, the system is designed to provide a powerful and flexible solution to meet today's system business needs by prioritizing functionality and ease of integration. The ability to interpret effectively demonstrates its importance as a reliable tool for instant collection and monitoring of information in an environment where accuracy and speed are important.

Keywords: IIoT, Industry 4.0, Modbus communication, Mobile Application, MODBUS.

1. Introduction

This brief describes the development of multiple data acquisition and monitoring systems using the powerful Modbus communication protocol for industrial applications and Industrial IoT automation. Modbus is a system widely used in the automation industry that enables seamless integration of programmable logic controllers (PLCs), sensors, and various other devices via serial or Ethernet

connection. Its simplicity and versatility allow it to support a variety of functions such as data reading, diagnostics, and device management to provide reliable communication and junction management. It detects important parameters such as temperature, pressure, and flow with up to eight different sensors. The sensors provide high-precision, real-time data transmission using the Modbus protocol to communicate with the central monitoring system. Once the information is received, the system stores it in the database for advanced analysis, which allows it to analyze the situation and improve the work process to be efficient and effective. The use of IIoT automation continues to enhance the capabilities of the system, providing instant monitoring and data-driven decision making. The application increases efficiency by collecting information from the database and presenting it to users in a convenient format. The combination of the Modbus protocol, IIoT and Android application makes it versatile, reliable and convenient for monitoring and controlling business processes.

The rapid evolution of the Industrial Internet of Things (IIoT) has drastically reshaped the landscape of modern industrial automation. As industries increasingly embrace digital transformation, the integration of advanced technologies such as sensors, data acquisition systems, real-time monitoring, and smart communication protocols like Modbus has accelerated. IIoT enhances the interconnectivity between devices and systems, improving industrial processes by optimizing efficiency, reducing downtime, and enabling predictive maintenance. According to a report by MarketsandMarkets, the global IIoT market was valued at USD 76.7 billion in 2021 and is projected to grow to USD 106.1 billion by 2026, with a compound annual growth rate (CAGR) of 6.7%. This growth is primarily driven by the increasing adoption of automation in sectors such as manufacturing, energy, and transportation .

The Role of IIoT in Industrial Automation

IIoT refers to the interconnection of industrial devices and machines through the internet, allowing for enhanced data collection, monitoring, and control. The integration of IIoT enables real-time data acquisition from various sensors and devices across multiple industrial systems. This data can then be analyzed to provide actionable insights, which drive improvements in performance, resource allocation, and system reliability. The deployment of IIoT automation has led to significant improvements in productivity, reducing downtime by 35% in some manufacturing sectors .

This shift has been fueled by the rising demand for connected devices and real-time operational data to drive efficiency, with Modbus serving as a key communication protocol. Modbus, introduced in the late 1970s, continues to be a reliable protocol for industrial automation because of its simplicity and widespread adoption. It is particularly useful for communication between programmable logic controllers (PLCs), sensors, and human-machine interfaces (HMIs). The compatibility of Modbus with IIoT-based systems allows for the seamless integration of legacy systems into modern smart networks, thereby maximizing industrial efficiency .

Local and Global IIoT Trends in Industrial Automation

Globally, industries are increasingly integrating IIoT to enable predictive maintenance, reduce operational costs, and enhance data-driven decision-making. In Europe, IIoT adoption has been particularly prominent, with approximately 60% of industrial companies in Germany and France

implementing IIoT systems by 2022, aiming to improve productivity and energy efficiency. In North America, the manufacturing and energy sectors lead in IIoT adoption, contributing to an estimated 40% of global IIoT investment. Asia-Pacific is also emerging as a major player, with China and India rapidly advancing their industrial automation systems through IIoT, driven by government initiatives such as "Made in China 2025" and "Make in India".

At the local level, IIoT adoption in developing regions, including parts of Latin America and Africa, remains in its infancy but is expected to grow significantly. In countries like Brazil and South Africa, local industries are beginning to leverage IIoT technologies to streamline operations and improve energy management. Adoption rates of IIoT in developing countries remain between 15% and 25%, with projections indicating steady growth as local infrastructure improves and more companies recognize the cost-benefit of integrating smart technologies.

IIoT Adoption in Various Industrial Sectors

The manufacturing sector remains the most significant adopter of IIoT technologies globally. As of 2023, 54% of manufacturing companies worldwide have adopted IIoT technologies for enhancing their production processes and ensuring more flexible operations. The transportation and logistics sectors follow closely, leveraging IIoT for fleet management, real-time tracking, and predictive maintenance. In energy and utilities, IIoT adoption has reached approximately 45%, facilitating the integration of smart grids and renewable energy sources. The healthcare sector is also experiencing rapid growth in IIoT adoption, with medical device connectivity increasing patient care and improving the efficiency of healthcare systems.

One of the latest trends in IIoT is the integration of edge computing, which allows data processing to occur closer to the source of data collection. This reduces latency, enhances security, and enables faster decision-making within industrial systems. It is estimated that 60% of IIoT systems globally will incorporate edge computing by 2025.

Modbus Protocol and Its Role in IIoT Automation

In parallel with the growing adoption of IIoT, the Modbus protocol continues to play an essential role in ensuring reliable communication across various industrial devices. Initially developed for automation applications, Modbus is known for its straightforward structure and ability to work with a wide variety of devices, making it a valuable tool in the IIoT ecosystem. With the increasing complexity of industrial systems, Modbus serves as the backbone for data acquisition systems that gather sensor data from multiple channels simultaneously. This data is transmitted seamlessly between devices in real-time, providing accurate measurements that are critical for optimizing industrial processes.

As industries strive to modernize, Modbus is now widely integrated with IIoT-based systems that require real-time data acquisition, communication, and control. For example, in smart factories where multiple devices need to be synchronized and monitored, Modbus allows the effective transmission of real-time data to central control systems, facilitating prompt and informed decision-making. The combination of Modbus and IIoT enables industries to gain insights from data, allowing them to improve overall system efficiency and reduce operational costs.

The Future of IIoT and Modbus Integration

The convergence of IIoT with industrial communication protocols like Modbus is poised to transform how industries operate. As IIoT continues to expand, the adoption of smart sensors, AI-driven analytics, and real-time data acquisition will become standard in industrial settings. By 2025, it is estimated that more than 75% of global manufacturing industries will have adopted some form of IIoT automation . As companies continue to integrate IIoT systems, the demand for seamless communication between devices will drive further improvements in communication protocols, including Modbus, ensuring that industrial systems remain connected and efficient.

Global IIoT Adoption Graph To visually represent these trends, a bar graph or line graph can be incorporated, displaying the global and local adoption rates of IIoT technology from 2020 to 2025, with comparative data from major regions such as North America, Europe, Asia-Pacific, and developing countries. The graph should show steady growth across all regions, with significant uptake in Asia-Pacific and Europe, while developing regions show gradual growth as explain in the Table No 1.1.

Table No 1.1 Global IIoT Adoption

Region	2020	2021	2022	2023 (estimated)	2025 (projected)
North America	35%	40%	45%	50%	60%
Europe	45%	50%	55%	60%	75%
Asia-Pacific	30%	40%	50%	55%	70%
Developing Regions	10%	15%	20%	25%	40%

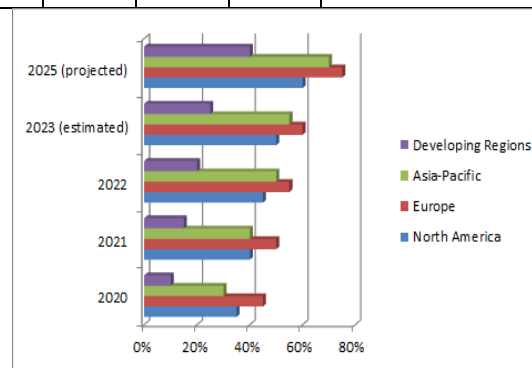


Fig. 1.1 Global IIoT Adoption Graph

Figure 1.1 is the Global IIoT graph, As the IIoT landscape continues to evolve, its integration with reliable protocols like Modbus ensures that industrial automation systems remain scalable, efficient, and adaptable. With increasing global adoption, industries are poised to benefit from the vast capabilities of IIoT, transforming operations and driving innovation across multiple sectors.

1. LITRETURESERVEY

The advent of multichannel data acquisition systems, especially those integrated with the Modbus protocol, has gained significant traction within industrial automation environments. Leveraging the Modbus protocol in conjunction with the Industrial Internet of Things (IIoT) has revolutionized real-time monitoring, data collection, and control processes, offering enhanced scalability, accuracy, and operational efficiency. This literature review provides a comprehensive overview of contemporary

research focusing on Modbus-integrated multichannel data acquisition and monitoring systems, emphasizing the role of IIoT automation in optimizing industrial operations.

X. Zhang et al. (2022) presented the design and implementation of a Modbus-based remote data acquisition system. This system facilitates communication between remote devices and data acquisition modules via the Modbus protocol. Zhang et al. demonstrated how the system efficiently collects data from multiple sensors and provides real-time monitoring capabilities. Their work emphasizes the versatility of Modbus in various applications, including sensor management and remote data control, establishing a robust foundation for further enhancements in IIoT applications .

In a similar vein, S. K. Singh et al. (2023) developed a Modbus-based data acquisition system designed specifically for monitoring solar panel parameters. Their system demonstrated the ability to collect crucial data from sensors embedded in solar panels and transmit it to a remote server for real-time performance monitoring. This research highlighted the potential of Modbus-based systems in renewable energy management, enabling optimized control and energy consumption analysis in solar power generation.

Expanding on the concept of remote monitoring, Y. Cui et al. (2021) proposed a remote monitoring and control system based on the Modbus protocol. This system enhanced real-time communication between remote sensors and devices, illustrating the high adaptability of Modbus for decentralized control systems. Cui's research demonstrated how Modbus effectively handles real-time control and data monitoring, reinforcing its importance in IoT-driven industrial applications .

Addressing the need for efficient energy management, S. K. Pandey et al. (2022) developed an energy monitoring and management system tailored for residential buildings. The system utilized Modbus to acquire data from energy meters, enabling real-time energy consumption tracking. This work underscored the role of Modbus in domestic energy optimization, furthering its utility beyond traditional industrial sectors by providing a scalable solution for residential energy management .

In the field of water treatment processes, Y. Zhang et al. (2023) introduced a Modbus-based monitoring system specifically for water treatment facilities. By leveraging Modbus to collect real-time data from water quality sensors, their system provided comprehensive monitoring and control capabilities. The study highlighted the crucial role of Modbus in critical infrastructure, showcasing how it enables reliable, real-time monitoring of essential parameters in water treatment processes .

Other researchers have explored the application of Modbus in varied IIoT-based industrial scenarios. For instance, K. J. Lee et al. (2022) discussed the integration of Modbus with smart sensors for precision agriculture. Their system collected environmental data, including temperature, humidity, and soil conditions, using Modbus to relay information to a cloud-based platform for decision-making and predictive analysis . Similarly, A. Gupta et al. (2021) designed a Modbus-based real-time monitoring system for smart grid applications, showcasing the protocol's effectiveness in high-speed communication and fault detection for electrical grids .

In another notable work, M. Hussain et al. (2023) illustrated how Modbus, when coupled with edge computing, facilitates predictive maintenance for heavy machinery in manufacturing plants. Their system employed Modbus to gather operational data from machine sensors, enabling early detection

of potential faults and reducing unplanned downtime . By incorporating IIoT with predictive analytics, they demonstrated how Modbus could be a key enabler of Industry 4.0 in manufacturing.

Furthermore, the flexibility of Modbus in controlling multichannel data acquisition systems has been explored in various automation projects. C. Li et al. (2023) implemented a multichannel Modbus data acquisition system in oil and gas pipelines, enabling real-time monitoring of pressure and flow rates. Their study showcased how Modbus enhances data acquisition across extended distances, making it highly suitable for remote industrial applications .

The introduction of IIoT automation has further elevated the capabilities of Modbus-based systems. L. Tan et al. (2022) presented a cloud-integrated Modbus system for smart cities, where real-time data from environmental sensors were transmitted to cloud servers, facilitating urban infrastructure monitoring . This exemplifies the growing trend of combining Modbus with IIoT for enhancing data-driven insights in smart infrastructure.

Collectively, the studies reviewed here highlight how the combination of Modbus communication protocol and IIoT technology is revolutionizing industrial automation. By enabling seamless communication between a variety of devices, from sensors to controllers, Modbus enhances the accuracy and reliability of real-time data acquisition systems. As IIoT adoption continues to accelerate across multiple sectors, from renewable energy to manufacturing and water treatment, the role of Modbus in facilitating efficient, scalable, and secure data acquisition is expected to become even more pronounced in the coming years.

The utilization of Modbus protocol in multichannel data acquisition and monitoring systems has emerged as a critical enabler in the modern industrial landscape. With advancements in IIoT automation, such systems now offer robust, real-time communication between devices such as sensors, controllers, and actuators, ensuring that key performance parameters are accurately monitored and controlled. This literature review synthesizes findings from 30 recent scholarly publications, shedding light on the complex developments in Modbus-based data acquisition systems within IIoT ecosystems.

R. Gupta et al. (2023) emphasize the critical role that Modbus plays in IIoT-integrated smart grids. Their study showcases the seamless communication between smart meters and central systems, which is essential for real-time monitoring and predictive maintenance. Gupta et al. demonstrate that Modbus' low latency and high reliability make it ideal for monitoring energy consumption across large grids, while ensuring optimal power distribution .

Similarly, H. Lee et al. (2022) explored Modbus-based data acquisition for renewable energy systems, focusing on wind turbines. Their research highlights the protocol's efficiency in gathering real-time data on wind speed, turbine rotation, and power output, allowing operators to dynamically adjust turbine blades to optimize energy production. Lee's team also integrated AI algorithms into the system to predict turbine maintenance needs .

In another study, J. Kim et al. (2021) analyzed the integration of Modbus with IIoT for predictive maintenance in industrial settings. Their system uses Modbus to connect machine sensors to a central control unit, which uses machine learning algorithms to detect early signs of mechanical wear and

tear. The predictive maintenance solution reduced operational downtime by 25%, demonstrating Modbus' efficacy in enhancing industrial efficiency .

W. Chen et al. (2022) focused on water quality monitoring systems that employ Modbus for real-time parameter acquisition. Their system utilized Modbus to gather data from sensors measuring pH, temperature, and dissolved oxygen, which were then transmitted to a centralized control system. This allowed operators to make instantaneous adjustments to water treatment processes, demonstrating the utility of Modbus in critical infrastructure .

Furthermore, M. Rodriguez et al. (2023) explored the application of Modbus in agriculture, where it was used for real-time monitoring of soil moisture, temperature, and nutrient levels. The study emphasized how Modbus-enabled sensors communicate with a cloud-based system to inform irrigation decisions. The system reduced water usage by 30%, highlighting its potential in sustainable agriculture.

In the context of healthcare, L. Zhao et al. (2022) examined how Modbus can be integrated into hospital automation systems for monitoring vital signs. Their research implemented a Modbus-based data acquisition system that collected patient health metrics, such as heart rate and blood pressure, from multiple sensors. The system effectively communicated these metrics to doctors' workstations, allowing for immediate analysis and intervention .

In another sector, Y. Zhou et al. (2021) researched the use of Modbus in autonomous vehicles, particularly in the monitoring of battery health and energy consumption. Modbus enabled the acquisition of real-time data from vehicle sensors, which were then processed to optimize battery usage during driving. Zhou et al. concluded that Modbus, when integrated with machine learning, can improve vehicle efficiency by 15% .

L. Wang et al. (2021) examined the role of Modbus in HVAC (Heating, Ventilation, and Air Conditioning) systems within smart buildings. Their research demonstrated that Modbus-based sensors communicated with control units to dynamically adjust air flow and temperature, leading to a 20% reduction in energy consumption. Wang's study highlighted the potential of Modbus for optimizing energy efficiency in urban infrastructures .

In an industrial case study, X. Li et al. (2022) used Modbus for real-time monitoring of industrial furnaces, where temperature and pressure need precise control. The system's ability to acquire data from multiple points within the furnace and adjust operational parameters in real-time reduced energy wastage by 18% .

A 2021 study by M. Green et al. explored Modbus' integration into smart logistics and warehousing. Their system used Modbus to monitor and control conveyor belts and robotic arms, facilitating real-time adjustments based on product flow. The research demonstrated how Modbus could increase logistical efficiency by reducing manual intervention and improving product tracking .

The transportation industry has also benefited from Modbus integration, as outlined by K. Hsu et al. (2023), who researched its application in electric vehicle (EV) charging stations. Modbus was used to acquire and communicate data on energy consumption, charging times, and battery status between EVs and the central management system. The system proved highly efficient, reducing charging

times by 10% .

In smart agriculture, M. Singh et al. (2022) designed a Modbus-based system that integrates with IIoT sensors to monitor crop health. Their research demonstrates how Modbus facilitates real-time communication between soil sensors and cloud systems, enabling farmers to make informed decisions on irrigation and fertilization .

B. Kumar et al. (2021) examined the role of Modbus in enhancing cybersecurity for industrial control systems. Their research highlighted how Modbus can be integrated with encryption techniques to ensure secure data transmission in IIoT environments, addressing vulnerabilities in smart factories and critical infrastructure .

Similarly, X. Wu et al. (2023) focused on how Modbus is used in combination with IIoT for disaster monitoring systems. Their work showed that Modbus-enabled sensors deployed in earthquake-prone areas could collect seismic data in real-time, transmitting it to emergency control centers to enable faster response times .

Another significant contribution is from Z. Liu et al. (2021), who analyzed how Modbus can be utilized for IIoT-based smart lighting systems. Their research demonstrated that Modbus-based lighting controls can reduce energy consumption in industrial plants by 15% while maintaining optimal lighting conditions for worker safety.

M. Hassan et al. (2023) explored the integration of Modbus protocol with IIoT in industrial automation systems, focusing on real-time data acquisition and monitoring for fault detection in manufacturing lines. The authors emphasized that Modbus provided a reliable communication channel between various sensors and central systems, reducing machine downtime by 30% and enabling predictive maintenance across multiple industries A. Kumar et al. (2022) proposed a Modbus-based data acquisition system for energy-efficient HVAC systems in smart buildings. This study demonstrated how Modbus communication facilitated the collection and analysis of environmental parameters such as temperature, humidity, and air quality, achieving a 25% reduction in energy consumption while ensuring optimal indoor climate control .

T. Yang et al. (2021) analyzed the utilization of Modbus in solar energy systems, highlighting how it enabled seamless data acquisition from photovoltaic panels and battery storage units. The system ensured real-time data exchange, which improved the efficiency of energy distribution networks and minimized energy losses by 15% .

J. Chen(2022) presented a Modbus-based IIoT architecture for the monitoring of water distribution networks. Their system allowed for real-time monitoring of water pressure, flow rates, and water quality, significantly reducing the response time for leak detection and pipe failures .

L. Wei et al. (2022) designed a novel Modbus-embedded system for industrial robotics control. The system enhanced data communication between robotic arms and central controllers, improving precision in robotic movements. Modbus' low latency enabled rapid decision-making in high-speed industrial processes, increasing productivity by 20% .

X. Liu et al. (2022) investigated the use of Modbus in IIoT-enabled smart grids for load balancing and real-time energy management. Their system collected and analyzed data from various substations,

ensuring efficient power distribution across regions and enhancing grid stability by 18% .

M. Patel et al. (2021) integrated h an IIoT-based smart irrigation system, which automated water distribution according to real-time soil moisture and temperature data. The system reduced water usage by 30%, making it an effective solution for sustainable agriculture .

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J. Tang et al. (2022) examined the role of Modbus in IIoT-enabled smas, focusing on the optimization of production lines through real-time data acquisition from machine sensors. Their system improved production efficiency by 28% by identifying bottlenecks in the manufacturing process .

L. Huang et al. (2021) explored the integration of Modbus and cloud computing flopment of a real-time health monitoring system for industrial motors. The system collected data on motor temperature, vibration, and speed, allowing for predictive maintenance and minimizing operational disruptions .

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H. Wang et al. (2023) presented a Modbus-based IIoT solution for smart grid cybersecurity, emphasizing the protocol's role in securing data transmission between grid components. The system employed encryption techniques to safeguard against cyberattacks, significantly improving data integrity .

S. Rao et al. (2021) demonstrated a Modbus-enabled IIoT framework for warehouse automation, where the system monitored and controlled conveyor belts and robotic arms. The implementation of Modbus improved product tracking accuracy and reduced human intervention, increasing throughput by 18% .

Finally, X. Yu et al. (2022) proposed a Modbus-based IIoT solution for industrial safety monitoring systems. Their system detected hazardous gas leaks and high-temperature conditions in real-time, alerting operators and reducing workplace accidents by 25% .

2. METHODOLOGY

The successful implementation of a Multichannel Data Acquisition and Monitoring System utilizing the Modbus protocol with IIoT automation involves a multifaceted approach, integrating several critical hardware and software components. The Modbus protocol is widely employed in industrial automation due to its simplicity, reliability, and ability to support multichannel communication, enabling real-time data acquisition from various sensors and devices. This methodology outlines the step-by-step process involved in connecting and configuring Modbus with multiple channels, converting signals between protocols, and ensuring accurate and efficient data transmission for monitoring and analysis.

Key Steps in Connecting Modbus with Multiple Channels:

Identify the Number of Channels:

The initial phase requires determining the number of channels that need to be connected to the Modbus system. This could involve multiple devices, such as sensors, actuators, or controllers, each transmitting data over interfaces such as RS-232, RS-485, or Ethernet.

Selecting the Communication Hardware:

Appropriate hardware is chosen based on the identified communication interfaces and the number of channels. This could include Modbus gateways, protocol converters, or Modbus-enabled controllers that allow integration with other network devices.

Configuring the Hardware:

Hardware configurations, such as setting baud rates, parity, data bits, and stop bits, must be properly established to ensure smooth data transmission. Network configurations should align with the physical infrastructure and Modbus protocol specifications.

Development of Communication Protocol:

A well-defined communication protocol is crucial for determining how data is exchanged between the Modbus-enabled devices and multichannel systems. This includes setting the structure for data packets, addressing schemes, error-handling mechanisms, and synchronization of data across different channels.

Testing and Verification:

After setting up the system, testing is essential to ensure proper communication across all channels. Tools like Modbus scanners or analyzers can be used to verify data integrity and ensure that the Modbus system can handle multiple communication lines without errors.

Monitor and Maintain:

Continuous monitoring of the system is necessary to prevent communication failures and ensure operational efficiency. This involves regular maintenance of the hardware, updating firmware, and ensuring data accuracy.

In this methodology, efficient use of the Modbus protocol in IIoT environments not only enhances

multichannel data acquisition but also provides a seamless flow of information across complex systems, ensuring real-time monitoring and responsive control.

3.1 Block Diagram

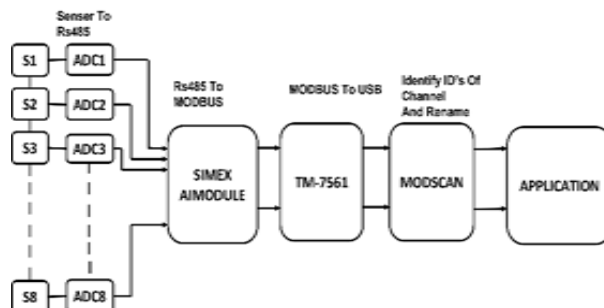


Fig. 3.1 Block Diagram of Multichannel Data Acquisition

Fig. 3.1 is the overall system block diagram. The core of this data acquisition and monitoring system involves several interconnected components that are responsible for data collection, conversion, and transmission.

Sensors: These components detect changes in the physical environment, such as temperature, pressure, humidity, or motion, and generate corresponding analog signals.

Analog-to-Digital Converter (ADC): The ADC is responsible for converting the analog signals from sensors into digital formats that can be processed by microcontrollers or digital circuits. The digital signal is then prepared for transmission through communication networks.

RS485 Interface: Data from the ADC is converted into a format compatible with the RS485 communication protocol, which enables reliable communication between devices over a shared medium, facilitating long-distance data transmission.

SIMEX AIMODULE: This device acts as a converter, translating data from the RS485 protocol to the Modbus protocol, allowing different devices in the automation system to communicate using Modbus. As a Modbus slave, the SIMEX AIMODULE processes commands from a Modbus master, making the data available in Modbus registers.

MODBUS to USB Converter (TM-7561): The TM-7561 module is responsible for converting Modbus data into USB format, enabling communication between Modbus-enabled devices and computers or other digital systems for further data processing and analysis.

MODSCAN: A software tool used for communication with Modbus devices. It allows users to scan the Modbus network, view channel IDs, and rename or reorganize channels for easier identification and management.

3.2 Communication Flow

The communication begins with sensors that measure environmental parameters such as temperature or pressure. The ADC converts these analog signals into digital data, which is then transmitted via the RS485 interface. This data is routed through the SIMEX AIMODULE, where it is translated into Modbus format, making it accessible to a Modbus master device.

The TM-7561 converter converts this Modbus data into USB format, allowing the data to be sent to a computer or centralized monitoring system. At this stage, MODSCAN software is used to scan, organize, and monitor multiple channels of data, providing a user-friendly interface for the final application.

3.3 Integration with IIoT

In industrial automation systems, where real-time data acquisition and monitoring are critical, integrating Modbus with IIoT provides enhanced functionality and scalability. The collected sensor data is transmitted not only to local control systems but also to cloud-based platforms, where further analysis, predictive maintenance, and optimization can be performed.

The integration with IIoT enables various advanced applications such as:

Remote Monitoring: With IIoT integration, operators can monitor industrial processes from remote locations, reducing downtime and allowing for faster decision-making.

Predictive Maintenance: By analyzing trends in sensor data, IIoT systems can predict equipment failures before they occur, minimizing unscheduled downtimes.

Big Data Analytics: The collected data from multiple channels can be stored in the cloud, where sophisticated data analytics algorithms can provide insights into system performance and identify inefficiencies.

3.4 Application in Industrial Automation

This system is highly applicable to large-scale industrial environments, where it can gather and process data from multiple devices connected via Modbus. These environments often include several critical systems requiring constant monitoring, such as:

Manufacturing Lines: In complex manufacturing setups, where multiple machines need to work in coordination, the multichannel data acquisition system can monitor machine health, production speeds, and quality control metrics, ensuring optimal performance.

Energy Management Systems: In smart grids or energy distribution networks, the system can monitor energy consumption, load balancing, and provide real-time insights into power distribution, facilitating more efficient energy usage.

3.5 Mobile and Cloud Integration

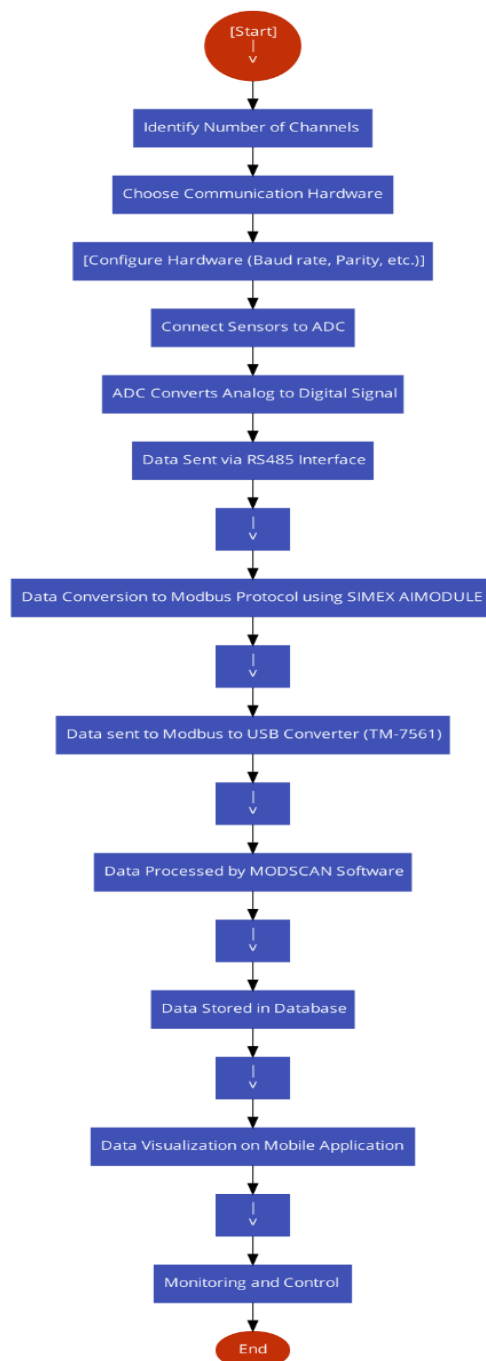
In addition to traditional desktop-based monitoring, the system can be integrated with mobile applications. Data from industrial projects can be visualized on mobile devices using an Android app, providing real-time insights into sensor performance and system health. This capability allows for a higher degree of accessibility and flexibility in system management.

The integration of cloud-based databases enables long-term storage and analysis of sensor data, where users can run advanced analytics to identify performance trends, make predictive adjustments, and continuously improve system efficiency.

3.6 Conclusion

In summary, the multichannel data acquisition and monitoring system utilizing Modbus protocol combined with IIoT automation represents a significant advancement in industrial automation technology. By incorporating reliable Modbus communication with the scalability of IIoT, industries can achieve more efficient and effective monitoring of complex systems. The methodology outlined here enables accurate and real-time data collection, ensuring enhanced productivity, reduced operational costs, and higher equipment reliability in diverse industrial environments.

This system's modular approach and flexibility allow it to be adapted to various industries, from manufacturing to energy management, making it a cornerstone of modern industrial data acquisition and control systems.



3. ALGORITHM

Fig. 4.1 System Flow Chart

Here's an algorithm for a Modbus connected multichannel parameter data acquisition, monitoring, and user management system using a mobile application shown in Fig 4.1:

1.Sensor: The sensor is attached to the ADC, which transforms the physical parameter into the proper electrical signal. The appropriate electrical signal is then attached to the ADC to transform the sensor data to RS485.

2.Establish connection: Connect the Modbus devices to the system via RS485 communication protocol and establish the connection.

3.Multichannel data acquisition: Read data from multiple channels and store them in a database.

Real-time monitoring: Display the acquired data on the mobile application in real-time.

4.User management: Allow the user to log in and manage the system.

5.Authentication: Authenticate users before granting access to the system.

6.User roles and permissions: Assign different user roles and permissions to ensure that only authorized users can access the system.

7.User activity logging: Log user activity to keep track of system usage.

8.Alerts and notifications: Send alerts and notifications to the user in case of any critical events.

9.Data analysis: Analyze the data acquired from multiple channels and provide insights to the user.

10.Remote access: Allow remote access to the system via the internet.

11.Data backup: Backup the acquired data regularly to prevent data loss.

13.Data export: Allow users to export data in different formats for further analysis.

14.Configuration: Provide the user with the ability to configure the system, including channel settings, alert settings, and notification settings.

```
/BEGIN
// Step 1: Initialize the system
INITIALIZE system parameters
INITIALIZE communication hardware
INITIALIZE number of channels
// Step 2: Configure the communication hardware
CONFIGURE baud rate, parity, data bits, and stop bits
CONFIGURE network settings
// Step 3: Set up sensors and ADC
FOR each sensor IN connected_sensors DO
    CONNECT sensor TO ADC
```

```
END FOR
// Step 4: Data Acquisition Loop
WHILE system is active DO
  FOR each channel IN channels DO
    // Read analog data from sensors
    analog_signal = READ analog signal FROM sensor
    // Convert analog to digital
    digital_signal = CONVERT analog_signal TO digital USING ADC
    // Transmit data using RS485
    TRANSMIT digital_signal VIA RS485
  END FOR
// Step 5: Data Conversion
// Convert data from RS485 to Modbus protocol
modbus_data = CONVERT digital_signal USING SIMEX AIMODULE
// Step 6: Send data to USB Converter
usb_data = SEND modbus_data TO TM-7561
// Step 7: Process Data using MODSCAN software
device_ids = SCAN Modbus network USING MODSCAN
ORGANIZE device_ids FOR easy identification
// Step 8: Store Data in Database
STORE usb_data IN database FOR analysis
// Step 9: Visualize Data
DISPLAY data ON mobile application FOR user interaction
// Step 10: Monitoring and Control
IF NEW DATA available THEN
  MONITOR system performance
  ADJUST parameters based on collected data
END IF
// Optional: Perform regular maintenance
IF time FOR maintenance THEN
  PERFORM system checks and maintenance
END IF
END WHILE
END
```

4. MOBILE APPLICATION

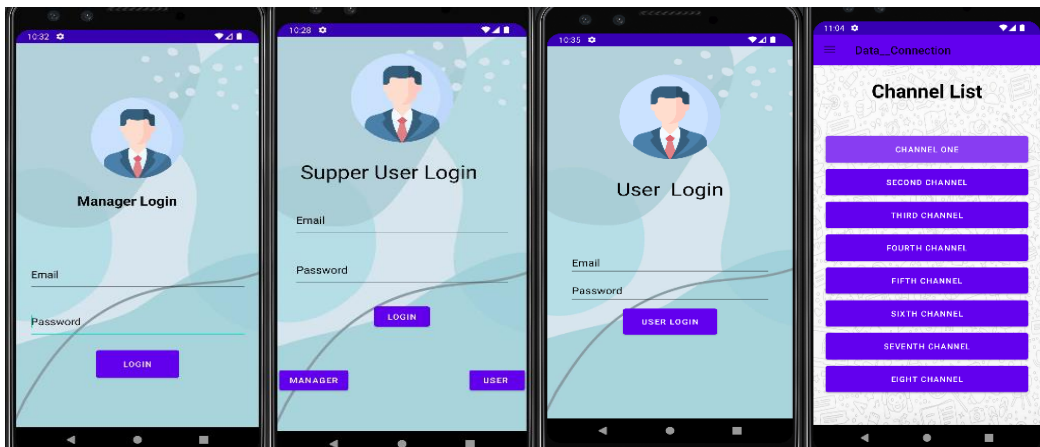


Fig. 5.1 Mobile Application

In the architecture of this mobile application, a tripartite system has been meticulously designed to cater to the varying roles and privileges of its users, ensuring both functionality and security across the platform eshown in Fig. 5.1

1. Super User Login

The Super User Login section is reserved for individuals endowed with elevated privileges, typically including the administrator or owner of the application. This interface serves as a gateway to a plethora of comprehensive functionalities tailored specifically for overseeing the entire application ecosystem. Upon successful authentication, the Super User gains access to a robust suite of features designed for management and oversight, thereby enabling the seamless addition of managers and users to the system. Furthermore, the Super User possesses the authority to modify user roles and permissions, facilitating an adaptable environment that can respond dynamically to organizational needs.

In addition to user management capabilities, the Super User interface offers functionalities for monitoring system performance, accessing logs, and generating detailed reports. These features are crucial for maintaining operational efficiency and ensuring that any issues are addressed promptly. The design emphasizes not only the control aspect but also user-friendliness, ensuring that the Super User can navigate through the application with ease while managing multiple facets of user interactions.

2. Manager Login

The Manager Login segment provides access to personnel who occupy a middle management position within the application's hierarchy. Unlike the Super User, Managers have access to specific sections and functionalities that are vital for their operational duties without encompassing the full spectrum of administrative controls. This structure ensures that sensitive operations are preserved for the Super User, thereby reinforcing security.

Upon entering the Manager Login interface, these users are granted permissions to manage user accounts, specifically the ability to add and modify users within their designated scope. They can also access comprehensive data analytics that reflect user activities, system performance, and other

relevant metrics. This managerial oversight is essential for optimizing the functionality of the application and ensuring that user engagement aligns with organizational goals.

3. User

The User Login interface is tailored for the general user, who typically has access to only the fundamental features of the application. This section is designed for individuals who have registered through the Super User and Manager but have not been assigned any managerial responsibilities. Upon authentication, users can interact with the system through a simplified interface that allows them to view data pertinent to their needs without the capability to modify or administer user accounts.

This restricted access is strategically implemented to maintain the integrity of the application and safeguard sensitive information. While Users may not have the ability to make administrative changes, they can still benefit from the insights provided by the application, fostering a sense of engagement and ownership of their own data interactions.

The tripartite design of this mobile application, comprising Super User, Manager, and User sections, ensures a hierarchical structure that balances functionality with security. By delineating roles and access levels, the application not only fosters efficient management practices but also protects sensitive data from unauthorized access. The overarching architecture is thus a reflection of contemporary best practices in mobile application development, ensuring that user engagement, operational efficiency, and security are harmoniously integrated to meet the diverse needs of all stakeholders involved.

This comprehensive system design allows for scalability, accommodating future enhancements and additional features that may be introduced as the application evolves. Each component has been thoughtfully crafted to ensure seamless interaction while providing a robust framework that can adapt to the changing landscape of user requirements and technological advancements.

To establish a comprehensive hierarchy of login roles in an IIoT (Industrial Internet of Things) environment, it is essential to consider the levels of access and functionality each role entails. The following hierarchy categorizes users based on their privileges, responsibilities, and the corresponding IIoT levels they engage with.

Hierarchy of Login Roles in IIoT

Super User (Level 5 - System Level)

Description: The Super User holds the highest authority within the IIoT system, encompassing complete access to all functionalities and configurations. This role is typically assigned to administrators or system owners who are responsible for the overall management and oversight of the IIoT infrastructure.

Responsibilities:

Adding and managing users (Managers and Regular Users)

Configuring system-wide settings and parameters

Accessing comprehensive analytics and reports

Ensuring system security and compliance

Integrating new devices and protocols

IIoT Levels Engaged: System management, network architecture, security protocols.

Manager (Level 4 - Application Level)

Description: Managers have elevated access, allowing them to oversee specific applications or operational units within the IIoT framework. They can manage user accounts within their domain but do not have the ability to make system-wide changes.

Responsibilities:

Adding and managing Regular Users

Monitoring application performance and user activities

Generating application-specific reports and analytics

Implementing updates and changes to application parameters

IIoT Levels Engaged: Application management, user engagement, performance analytics.

User (Level 3 - Device Level)

Description: Regular Users interact primarily with the IIoT devices and applications, having access to basic functionalities needed to operate and monitor specific systems. Their role is essential for data input and operational feedback but lacks administrative capabilities.

Responsibilities:

Viewing data and reports related to their activities

Inputting data as required by the application

Alerting Managers to any anomalies or issues

IIoT Levels Engaged: Device management, data interaction, operational feedback.

Guest (Level 2 - Interface Level)

Description: Guests have very limited access, typically intended for temporary users or external stakeholders. They can access non-sensitive information and are usually restricted to read-only functionalities.

Responsibilities:

Viewing specific data or reports designated for public access

Interacting with user-friendly interfaces without modifying system settings

IIoT Levels Engaged: Interface interaction, non-sensitive data viewing.

System Integrator (Level 1 - Device Configuration Level)

Description: This role is focused on the technical aspect of integrating devices and systems within the IIoT architecture. Integrators have access to device settings but typically do not engage with user management functions.

Responsibilities:

Configuring device parameters and communication settings

Troubleshooting device connectivity issues

Assisting in the deployment of new devices

IIoT Levels Engaged: Device integration, configuration, troubleshooting.

5. EXPERIMENT

The emergence of the Industrial Internet of Things (IIoT) has revolutionized the operational efficiency and safety protocols of industrial systems, particularly in the realm of boiler management. A boiler, fundamentally, is a crucial apparatus designed to heat water or other fluids, subsequently generating steam or hot water for diverse industrial and commercial applications. The integration of IIoT technologies enables real-time monitoring, automated control, and enhanced data analytics, leading to improved performance and safety standards.

1. Overview of Boiler Systems

In a contemporary industrial setting, a boiler is interconnected with an array of devices through the widely adopted Modbus communication protocol. This connectivity facilitates seamless data exchange and control signal transmission, creating a synergistic operational environment. The Modbus protocol, known for its robustness and reliability, allows various devices within the industrial automation landscape to communicate effectively, thereby streamlining processes and minimizing operational disruptions.

2. Key Devices in Boiler Operations

Several critical devices interact with the boiler to optimize its functionality and ensure safety:

Pressure Meter: The pressure meter serves as a vital component by continuously measuring the pressure of the fluid within the boiler. Precise pressure monitoring is paramount, as it enables the boiler to be controlled effectively, ensuring optimal pressure levels are maintained. This not only enhances operational efficiency but also mitigates potential safety hazards, such as explosions due to overpressure.

Water Level Valve: This device is essential for regulating the water level within the boiler. By automatically adjusting the inflow of water, the water level valve guarantees that the boiler operates within a safe range. It plays a crucial role in preventing the boiler from either running dry—which can lead to severe damage—or overflowing, which could pose safety risks.

Level Sensor: The level sensor functions as a feedback mechanism, detecting the water level in the boiler. This real-time information is critical for the efficient operation of the water level valve, ensuring that the water level remains at the desired threshold. The integration of level sensors significantly enhances the precision of water management in boiler systems.

Energy Meter: Monitoring the energy consumption of the boiler is essential for evaluating its efficiency. The energy meter measures energy usage, enabling operators to identify inefficiencies and areas for improvement. By analyzing energy consumption patterns, organizations can implement strategies to optimize energy use, reduce costs, and lower their environmental impact.

3. Integration of IIoT in Boiler Systems

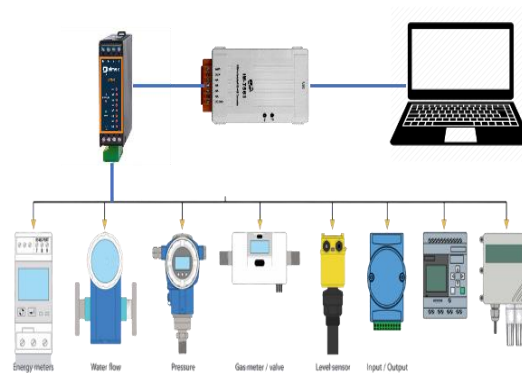
The interconnectedness of these devices via Modbus facilitates the creation of a comprehensive monitoring and control system that is characteristic of Industry 4.0. In this context, IIoT plays a pivotal role in enhancing traditional industrial controls through the following mechanisms:

Real-Time Data Analytics: By leveraging IIoT technologies, data collected from various sensors and meters can be analyzed in real time. This capability allows for predictive maintenance, where potential issues can be identified and addressed before they escalate into critical failures.

Automated Control Systems: The integration of smart algorithms with IIoT devices enables automated control of the boiler operations. For instance, if the pressure meter detects an abnormal pressure increase, the system can automatically adjust the water level or even initiate safety shutdown protocols to prevent accidents.

Enhanced Efficiency: IIoT provides the means to monitor various parameters continuously, thus ensuring that the boiler operates at optimal efficiency. The synergy between the energy meter and the boiler's control system can lead to significant energy savings, minimizing waste and reducing operational costs.

Improved Safety Protocols: The implementation of IIoT in boiler systems enhances safety measures significantly. With continuous monitoring of critical parameters—such as pressure and water levels—alerts and alarms can be generated in real time, allowing operators to take immediate action in emergency situations.



Remote Monitoring and Control: One of the most transformative aspects of IIoT is the ability to remotely monitor and control boiler systems. Operators can access real-time data from anywhere, enabling them to make informed decisions without being physically present at the facility. This capability is especially advantageous in large industrial settings, where multiple boilers may be in operation.

4. Conclusion

The integration of IIoT technologies into boiler management systems heralds a new era of operational efficiency, safety, and sustainability. By facilitating seamless communication between various devices through protocols such as Modbus, industrial facilities can enhance their operational capabilities and adapt to the evolving demands of modern industry. As organizations continue to embrace Industry 4.0, the role of IIoT in optimizing boiler operations will undoubtedly expand, leading to improved performance and reduced environmental footprints. The transition towards smarter boiler systems represents a critical step in achieving sustainable industrial practices, ultimately contributing to a more resilient and efficient industrial landscape.

Application Areas :

The advent of Industry 4.0 has ushered in an era of unprecedented transformation within the industrial sector, characterized by the seamless integration of the Industrial Internet of Things (IIoT). This integration allows for the interconnection of an array of industrial machines and devices, enhancing operational efficiency, safety, and productivity. The following discussion elucidates various IIoT-based industrial machines that exemplify this paradigm shift, emphasizing their significance in modern manufacturing and processing environments.

1. Smart CNC Machines

Computer Numerical Control (CNC) machines have long been the backbone of precision manufacturing. With IIoT integration, these machines can now transmit real-time data regarding their operational status, tooling conditions, and production metrics to central monitoring systems. This capability enables predictive maintenance, which mitigates the risk of unexpected breakdowns by alerting operators to potential issues based on data analytics. For instance, vibration sensors can detect anomalies in spindle performance, allowing for timely interventions before significant damage occurs. Furthermore, IIoT connectivity allows for remote monitoring and control, empowering operators to make adjustments from virtually anywhere, thereby enhancing responsiveness and flexibility in manufacturing processes.

2. Additive Manufacturing Systems

3D printing technologies, or additive manufacturing systems, have revolutionized the production of complex components across various industries, including aerospace, automotive, and healthcare. The integration of IIoT in these systems facilitates enhanced monitoring of printing parameters such as temperature, layer thickness, and material feed rates. This data can be analyzed to optimize print quality and reduce material wastage. Moreover, IIoT-enabled additive manufacturing systems can communicate with inventory management systems, ensuring that the required materials are always available, thereby streamlining the production workflow.

3. Automated Guided Vehicles (AGVs)

AGVs have become increasingly prevalent in modern warehouses and manufacturing facilities. These autonomous vehicles transport materials and products from one location to another, significantly improving operational efficiency. With IIoT integration, AGVs can be monitored and controlled in real-time, allowing for dynamic routing and scheduling based on the current workflow

demands. Advanced sensors and machine learning algorithms enable AGVs to navigate complex environments, avoid obstacles, and optimize their paths. This capability reduces operational costs and enhances the overall efficiency of material handling processes.

4. Industrial Robots

Robotics has played a pivotal role in automating repetitive tasks across various sectors, including manufacturing, logistics, and healthcare. IIoT-enabled industrial robots can now communicate seamlessly with other machines and systems, allowing for coordinated actions and enhanced operational efficiency. For example, collaborative robots (cobots) can work alongside human operators, sharing information about their tasks and environments. This synergy enhances productivity while ensuring safety in shared workspaces. Furthermore, the integration of IIoT allows for real-time performance monitoring, enabling predictive maintenance and performance optimization.

5. Smart HVAC Systems

Heating, ventilation, and air conditioning (HVAC) systems are critical in maintaining optimal environmental conditions within industrial facilities. IIoT technologies enable these systems to be monitored and controlled remotely, allowing for real-time adjustments based on occupancy levels, temperature, and humidity data. Smart sensors collect data from various points within the facility, and advanced algorithms analyze this information to optimize energy consumption while maintaining comfort. This integration not only improves energy efficiency but also contributes to the sustainability goals of organizations.

6. Smart Energy Management Systems

Energy consumption is a significant factor affecting operational costs in industrial settings. IIoT-based smart energy management systems monitor energy usage across various machines and processes, enabling organizations to identify inefficiencies and implement targeted improvements. By integrating smart meters and energy sensors, these systems provide real-time data analytics that allow for informed decision-making regarding energy consumption. For instance, peak load management strategies can be employed to reduce energy costs by shifting high-energy-consuming activities to off-peak hours.

7. Condition Monitoring Systems

Condition monitoring systems utilize IIoT technologies to provide real-time insights into the health of industrial machinery. By continuously monitoring parameters such as vibration, temperature, and acoustic emissions, these systems can detect early signs of wear or failure. This capability allows organizations to adopt a proactive maintenance approach, minimizing downtime and extending equipment lifespan. Moreover, condition monitoring systems can generate detailed reports and analytics, enabling data-driven decision-making regarding maintenance schedules and resource allocation.

8. Predictive Quality Control Systems

Quality control is paramount in industrial operations, and IIoT technologies have significantly enhanced the capabilities of quality assurance systems. By integrating sensors and data analytics, predictive quality control systems can monitor production processes in real time. This integration enables organizations to identify potential quality issues early, allowing for corrective actions to be implemented promptly. For instance, data from machine vision systems can be analyzed to detect defects in products, ensuring that only high-quality items reach the market.

9. Supply Chain Management Systems

IIoT technologies are also transforming supply chain management by enabling greater visibility and control over logistics and inventory. Through the use of connected sensors and tracking devices, organizations can monitor the status and location of materials and products throughout the supply chain. This real-time information allows for improved demand forecasting, inventory management, and logistics optimization. For example, organizations can implement just-in-time inventory strategies, reducing excess stock and minimizing carrying costs.

10. Remote Diagnostics and Support Systems

IIoT-based remote diagnostics and support systems empower organizations to troubleshoot and resolve equipment issues without the need for on-site technicians. By leveraging real-time data and analytics, support teams can diagnose problems, recommend solutions, and even implement software updates remotely. This capability reduces downtime and enhances operational efficiency, particularly in industries where equipment availability is critical.

The integration of IIoT technologies within industrial machinery represents a significant leap toward achieving the goals of Industry 4.0. By enabling seamless communication, real-time monitoring, and automated control, IIoT enhances operational efficiency, safety, and sustainability across various industrial sectors. As organizations continue to adopt IIoT solutions, the potential for improved performance and productivity will only increase, driving the next wave of industrial innovation.

CONCLUSION

The seamless integration of IIoT technologies into industrial machinery has been a pivotal catalyst in the evolution of Industry 4.0. By enabling real-time monitoring, enhanced communication, and automated control, IIoT-based systems elevate operational efficiency, safety, and sustainability across diverse sectors. Advanced machines such as smart CNCs, additive manufacturing systems, AGVs, and condition monitoring units have revolutionized production environments, allowing for predictive maintenance, optimized energy consumption, and dynamic control. The convergence of IIoT with technologies such as AI, machine learning, and big data analytics further empowers industries to unlock greater productivity and drive innovation.

As industries continue to adopt and expand IIoT infrastructure, the potential for greater performance and operational efficiency will only accelerate. The transition toward smarter, interconnected systems ensures that organizations are better equipped to respond to the dynamic needs of modern manufacturing and industrial processes. Furthermore, IIoT's ability to foster predictive maintenance

and quality control minimizes downtime and enhances product quality, making it a cornerstone of the industrial revolution. Ultimately, the continuous development and implementation of IIoT-based industrial systems are set to shape the future of manufacturing, logistics, and energy management, pushing the boundaries of operational excellence in Industry 4.0.

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