5 Transforming Industry 5.0

Real Time Monitoring and Decision Making with IIOT

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5.1 INTRODUCTION TO INDUSTRY 5.0: UNLEASHING THE POWER OF IIOT TRANSFORMATION

In the era of Industry 5.0, the convergence of industrial processes with advanced technologies like the Industrial Internet of Things (IIoT) has opened up new avenues for real-time and decision-making in industrial settings. The ability to gather, analyze, and visualize data in real time through interactive dashboards has revolutionized how industries operate, enabling agile responses, improved efficiency, and informed decision-making. The transformative potential of decision-making and real-time monitoring with IIoT dashboards in the framework of Industry 5.0 and its impact on various aspects of industrial operations are briefed along with the answers to the questions listed below:

- What are the key technologies involved in the transformation from Industry 4.0 to Industry 5.0?
- How does IIoT contribute to Industry 5.0?
- What is the significance and impact of real-time monitoring in IIoT?

5.1.1 Embracing the Evolution: Industry 4.0 to Industry 5.0

Both Industry 4.0 and 5.0 represent significant advancements in industrial technologies and the integration of digital systems. Here's an overview of the technologies used in each era:

Industry 4.0, in other words, the 'Fourth Industrial Revolution', brought about the convergence of traditional manufacturing processes with digital technologies [1]. The key technologies used in Industry 4.0 are shown in Figure 5.1.

The Industry 5.0 represents next phase of industrial evolution, emphasizing human-machine collaboration and the integration of intelligent systems. While Industry 5.0 figures upon the technologies of past Industry 4.0, it introduces new elements to

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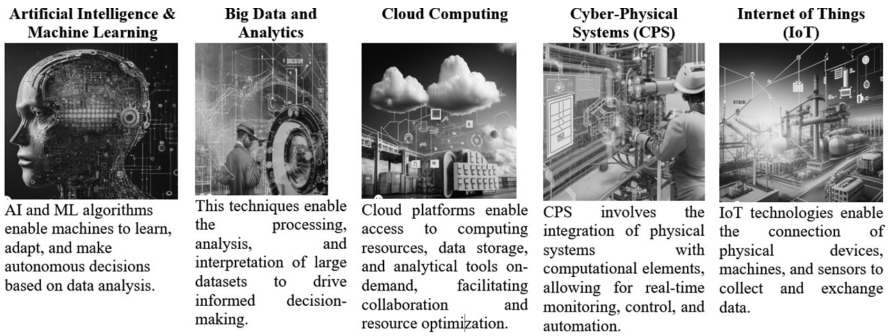

FIGURE 5.1 Major key components of Industry 4.0.

enhance the humans and machine interaction. Key technologies with recent advancements in Industry 5.0 are shown in Table 5.1.

Edge Computing: As the volume of data generated by IoT devices increases, edge computing allows for data analysis and processing to be performed faster to the source. It decreases latency, enables quick decision-making process, and reduces necessity on cloud-infrastructure. Some of the following examples in Table 5.2 represent significant achievements in the field of edge computing [8] within the context of Industry 5.0.

Additive Manufacturing (3D Printing): Additive manufacturing technologies enable the creation of complex components and products through layer-by-layer construction. This flexible and customizable manufacturing approach offers cost savings, rapid prototyping, and on-demand production capabilities [10].

Sustainable Technologies: Industry 5.0 places a strong emphasis on sustainability and environmentally friendly practices. Technologies in Figure 5.2 such as renewable energy systems, energy-efficient processes, and circular economy principles are incorporated to reduce environmental impact and promote sustainable development [11].

5.2 INDUSTRY 5.0: THE NEXT FRONTIER OF INDUSTRIAL REVOLUTION

Fifth Industrial Revolution (Industry 5.0) is a concept that emphasizes the integration of human intelligence with advanced technologies to produce more collaborative and sustainable industrial environment. The IIoT plays a crucial role in realizing the vision of Industry 5.0 by enabling the seamless connection, communication, and data exchange between machines, systems, and humans in industrial settings. Here are some ways in which IIoT contributes to Industry 5.0 [12].

- **Interconnectivity**: IIoT connects devices, sensors, machines, and systems, enabling real-time data flow for better visibility and control.
- **Data-Driven Insights**: IIoT generates vast data that can be analyzed to optimize processes, improve efficiency, and predict maintenance needs.
- **Smart and Autonomous Systems**: IIoT enables the deployment of connected machines and robots for decentralized decision-making and adaptive production.

TABLE 5.1
Key Technologies and Advancements in Industry 5.0

Key Technology	Advancements	Remarkable Achievement
Human-machine interaction (HMI) in Industry 5.0	Natural Language Processing (NLP) advancements	Significant advancements have been made in NLP, allowing machines to understand and process human language more effectively. This has led to the development of voice-activated assistants like Amazon Alexa and Apple Siri, revolutionizing the way humans interact with machines [2].
	Augmented Reality & Virtual Reality (AR&VR)	AR and VR technologies have been applied to various industries, enabling immersive experiences and enhancing human-machine collaboration. In manufacturing, for example, AR glasses have been used to guide workers through complex assembly processes, improving efficiency and reducing errors [3].
	Gesture recognition and motion tracking	Gesture recognition and motion tracking technologies have advanced, allowing machines to interpret human gestures and movements accurately. This enables intuitive interactions with machines, such as gesture-based controls for devices and robots [4].
	Brain-computer interfaces	BCIs have shown promising advancements, enabling direct communication between the human brain and machines. Researchers have developed systems that allow individuals with paralysis to control robotic limbs or communicate through thought commands [5].
	Emotion recognition and adaptive interfaces	Advancements in emotion recognition technology have allowed machines to recognize and react to social emotions. This enables much personalized with adaptive interfaces that can adjust their behavior based on the user's emotional state, leading to improved user experiences [6].

(*Continued*)

TABLE 5.1 (*Continued*)
Key Technologies and Advancements in Industry 5.0

Key Technology	Advancements	Remarkable Achievement
Collaborative robotics in Industry 5.0	Universal robots UR5 (2008)	Universal Robots introduced the UR5, a lightweight collaborative robot that was one of the first successful commercially available cobots. It offered easy programming, safety features, and the ability to work together with humans devoid of the need for protective barriers
	KUKA LBR IIWA (2013)	KUKA introduced the LBR IIWA (Intelligent Industrial Work Assistant), which became one of the early collaborative robots capable of human-like sensitivity and dexterity. It enabled safer interactions between humans and robots in industrial environments.
	Rethink robotics Baxter and Sawyer Year: 2012 (Baxter), 2015 (Sawyer)	Rethink Robotics introduced Baxter and later Sawyer, collaborative robots designed for manufacturing and assembly tasks. They featured advanced sensing, adaptable grippers, and intuitive user interfaces, enabling easy programming and human-robot collaboration.
	ABB YuMi (2015)	ABB introduced YuMi, a dual-arm co-operative robot specifically developed for minor parts assembly. It was equipped with vision systems, precise motion control, and advanced safety features, allowing it to work safely alongside humans on intricate assembly tasks.
	Ford's collaborative robots	Ford Motor Company implemented collaborative robots in their manufacturing processes, demonstrating how human-robot collaboration can enhance productivity and efficiency. These robots worked alongside human operators, assisting with tasks such as lifting heavy objects and repetitive assembly operations [7].

TABLE 5.2
Significant Achievements in Industry 5.0 in Edge Computing

Technology	Advancements in Industry 5.0
Fog computing concept	Cisco introduced the concept of fog computing, which later became associated with edge computing. Fog computing aimed to extend cloud computing capabilities to the network's edge, bringing computation, storage, and networking resources closer to the data source.
Microsoft azure IoT edge	Microsoft introduced Azure IoT Edge, a platform that enables the deployment and management of cloud services on edge devices. It allows for data processing and analytics to occur at the edge, improving responsiveness, reducing bandwidth usage, and addressing connectivity challenges.
Siemens' industrial edge	Siemens launched the Industrial Edge platform, which aimed to bring real-time data processing and analytics capabilities to the edge of industrial networks. The platform enabled decentralized computing, reducing latency and enabling faster decision-making in industrial settings.
Edge AI chipsets	Various technology companies, including Intel, NVIDIA, and Qualcomm, have developed specialized edge AI chipsets. These chipsets are designed to provide high-performance AI inference capabilities at the edge, enabling real-time data analysis and decision-making without relying solely on cloud resources.
Edge computing in autonomous vehicles	Edge computing plays a crucial role in enabling real-time processing and decision-making in autonomous vehicles. By bringing computational power closer to the vehicle, edge computing facilitates low-latency data analysis, enhancing safety, and enabling autonomous functionalities [9].

FIGURE 5.2 Sustainable technologies in Industry 5.0.

- **Collaborative Human-Machine Interaction**: IIoT facilitates interaction through AR and VR, enhancing productivity, safety, and decision-making.
- **Predictive Maintenance and Resource Optimization**: IIoT continuously monitors equipment, predicts failures, minimizes downtime, and optimizes resource utilization.
- **Enhanced Supply Chain management**: IIoT provides real-time visibility and traceability, improving logistics, reducing delays, and enhancing efficiency.

5.2.1 Empowering Industry 5.0: Harnessing the Potential of IIoT

Real-time monitoring in industrial settings offers numerous advantages and has significant implications for various aspects of operations. Here are some advantages and implications of real-time monitoring [13]:

- **Improved Operational Efficiency**: Real-time monitoring enables continuous tracking of critical parameters such as production rates, energy consumption, and equipment performance, allowing for timely identification of inefficiencies and bottlenecks. This facilitates proactive decision-making, resource optimization, and process improvements [14].
- **Enhanced Quality Control**: Real-time monitoring enables the detection of deviations or anomalies in product quality during the manufacturing process. This allows for immediate corrective actions, reducing the risk of producing defective products and improving overall quality control [15].
- **Predictive Maintenance**: Real-time monitoring of equipment and machine data enables the implementation of predictive maintenance strategies. By analyzing real-time sensor data and identifying patterns or anomalies, maintenance activities can be scheduled proactively, minimizing downtime, and reducing maintenance costs [16].
- **Improved Safety and Risk Mitigation**: Real-time monitoring of environmental factors, worker behavior, and equipment conditions enhances safety management. It enables the timely identification of potential hazards, allowing for immediate interventions and reducing the risk of accidents or incidents [17].
- **Data-Driven Decision-Making**: Real-time monitoring provides access to real-time data, empowering decision-makers with accurate and up-to-date information. This enables data-driven decision-making, allowing for agile responses to changing conditions, optimizing processes, and driving continuous improvement [18].

5.2.2 Real-Time Monitoring in Industry 5.0: A Comprehensive Literature Review

Real-time monitoring with IIoT dashboards in Industry 5.0 refers to the use of IIoT technologies [19] and dashboards to collect, analyze, and visualize real-time data for monitoring and decision-making in industrial settings [20]. It combines the connectivity of IIoT devices, sensors, and systems with the power of data analytics and visualization to enable real-time insights, proactive maintenance, and efficient resource management [21].

The following literature surveys provide comprehensive reviews of the current state of research, advancements, challenges, and future directions related to real-time monitoring with IIoT dashboards [22] in the background of Industry 5.0.

The challenges in implementation of IIoT technologies in industrial settings have gained significant momentum over the years [23]. This advancement has allowed for the collection of real-time data from various sensors and devices deployed in

TABLE 5.3
Notable Advancements and Overview of IIoT Technologies

Era	IIoT Technologies
Early stages (2000s–2010s)	During this period, the concept of IIoT began to emerge, highlighting the integration of internet-connected devices and industrial processes. Companies and industries started recognizing the potential benefits of deploying IIoT technologies to optimize their operations and improve efficiency.
Growth and expansion (2010s–2020s)	In the early 2010s, the adoption of IIoT technologies started to gain momentum, with industries embracing the concept to enhance their processes. Organizations began deploying sensors, devices, and network infrastructure to enable the collection of real-time data from industrial assets. The advancements in wireless communication and networking technologies, along with the decreasing cost of sensors, contributed to the wider adoption of IIoT in industrial settings.
Industrial transformation (2020s–Present)	The current period marks a significant shift toward Industry 4.0 and Industry 5.0, where IIoT plays a central role in driving digital transformation. The adoption of IIoT technologies enables industries to gather real-time data from machines, equipment, and other assets, providing insights into performance, efficiency, and predictive maintenance. The integration of IIoT with cloud computing, edge computing, and data analytics further enhances the capabilities of real-time data collection and analysis in industrial settings. Industries across various sectors, including manufacturing, energy, transportation, and healthcare, have embraced IIoT to optimize processes, improve productivity, and reduce operational costs.

industrial environments [24]. The following summary in Table 5.3 provides a detailed overview of the adoption of IIoT in industrial settings, along with notable advancements and their respective years [23–26].

In 2011, the term "Industry 4.0" was introduced, marking the emergence of the Fourth Industrial Revolution. Industry 4.0 is categorized by the incorporation of cyber-physical systems, IoT-related technologies, and data-driven technologies in industrial processes. This advancement has paved the way for the digital transformation of industries, enabling the seamless connection of machines, devices, and systems, and leveraging real-time data analytics to enhance operational efficiency, productivity, and decision-making in industrial settings [27].

The adoption of IIoT in industrial settings has paved the way for real-time monitoring, data-driven decision-making, and the transformation of traditional industries into intelligent, connected ecosystems by using certain IIoT principles, processes and protocols [28]. The continuous advancements in IIoT technologies, along with the increasing availability of scalable solutions, have further accelerated the adoption and integration of IIoT in industrial environments. The adoption of IIoT technologies gained momentum, enabling the collection of real-time data from various sensors and devices deployed in industrial environments [29]. Table 5.4 depicts various industries with its advanced technologies and applications [30].

TABLE 5.4
Various IIoT Advancements in Different Industries

Industry	Advancement	Applications
Manufacturing industry	IIoT technologies enable real-time data collection from sensors embedded in manufacturing equipment, machines, and production lines.	In a manufacturing plant, IIoT sensors installed on production equipment can gather data on parameters such as temperature, pressure, vibration, and energy consumption. This real-time data allows for predictive maintenance, optimized resource allocation, and improved overall equipment effectiveness (OEE).
Energy industry	IIoT facilitates the collection of data from energy infrastructure, enabling real-time monitoring and optimization of energy consumption.	Smart energy grids equipped with IIoT sensors can monitor energy generation, distribution, and consumption. This real-time data enables utilities to identify inefficiencies, optimize energy distribution, and implement demand-response mechanisms for efficient energy management.
Transportation and logistics industry	IIoT enables real-time tracking and monitoring of assets, vehicles, and goods throughout the supply chain.	Connected sensors embedded in vehicles, shipping containers, and warehouses provide real-time visibility into the location, condition, and status of goods. This helps optimize route planning, minimize delivery delays, and enhance supply chain efficiency.
Healthcare industry	IIoT facilitates remote patient monitoring and real-time data collection from medical devices.	Wearable devices and medical sensors connected through the IIoT enable continuous monitoring of vital signs, patient activity, and medication adherence. This real-time data enables healthcare professionals to remotely monitor patients, make timely interventions, and provide personalized care.
Agriculture industry	IIoT technologies allow for precision agriculture and real-time monitoring of crops, soil conditions, and irrigation systems.	IoT sensors placed in the field collect data on soil moisture, temperature, and nutrient levels. This information is used to optimize irrigation schedules, apply fertilizers precisely, and monitor plant health, leading to improved crop yields and resource efficiency.

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TABLE 5.4 (*Continued*)
Various IIoT Advancements in Different Industries

Industry	Advancement / Applications
Technology	**Description**
Wireless protocols (i) Wi-Fi	Enables high-speed wireless communication within a limited range, typically used for local area networking (LAN) applications.
Wireless protocols (ii) Bluetooth	Provides short-range wireless connectivity between devices, commonly used for low-power IoT devices and sensor networks.
Wireless protocols (ii) Zigbee	Designed for low-power, low-data-rate wireless communication over short distances, suitable for IoT applications with a large number of nodes.
Cellular networks 2G, 3G, 4G, and 5G:	Cellular networks offer wide-area coverage and provide reliable connectivity for IoT devices in remote or mobile applications. Each generation offers increased data rates, lower latency, and improved network capacity.
Ethernet	Ethernet is a wired networking technology that allows for high-speed and reliable data transmission over local area networks (LAN) and wide area networks (WAN). It is commonly used for industrial automation and control systems.
LoRaWAN - long range wide area network	LoRaWAN is a low-power wide-area network protocol that provides support to long-range communiqué for IoT system and devices. It is very apt for applications which need higher range with low power consumption, such as smart cities and agricultural monitoring.
MQTT - Message queuing telemetry transport	MQTT is a light weight messaging and transporting protocol intended for efficient and reliable data transfer between devices and servers. It is widely used in IoT applications, including IIoT, where low bandwidth and limited resources are a concern.
Edge computing	Edge computing encompasses analyzing data at network edge which is quite nearer to the data source. It is an alternative to rely only on cloud-based servers. It reduces dormancy, advances decision-making and real-time monitoring process, and reduces bandwidth requirements.
Industrial ethernet protocols	Specific industrial Ethernet protocols, such as Modbus TCP/IP, PROFINET, and EtherNet/IP, are widely used in industrial automation and control systems to enable real-time data exchange and communication between devices and machines.

IIoT dashboards were developed to provide real-time visualization and monitoring of industrial data. These dashboards present key performance indicators (KPIs), analytics, and insights in an easily understandable format, empowering decision-makers with real-time information [26]. IIoT dashboards evolved to incorporate advanced techniques in data analytics, like machine learning and predictive analytics, to derive actionable comprehensions from real-time data. This integration enables proactive decision-making and facilitates predictive maintenance, quality control, and resource optimization [27].

IIoT dashboards saw advancements in terms of user interface design, interactive features, and customizable visualization options. These enhancements improve the user experience, making it easier for operators and decision-makers to understand complex industrial data and take prompt actions [28].

IIoT dashboards started integrating with cloud platforms and edge computing technologies [29]. Cloud integration enables scalable storage, analysis, and remote access to industrial data, while edge computing brings real-time processing and decision-making capabilities closer to the data source [30].

5.3 LEVERAGING IIOT FOR REAL-TIME DATA COLLECTION AND ANALYSIS: CUTTING-EDGE METHODOLOGIES

IIoT for real-time data collection and analysis involves several steps of setting up an industrial IoT dashboard [31]. The general steps involved in the process are shown in Figure 5.3.

5.3.1 Defining Objectives and Uncovering Use Cases for IIoT Implementation

Clearly define the objectives and goals of leveraging IIoT for real-time data collection and analysis in specific industrial architecture context [32]. Identify the use cases where real-time data insights can bring the most value and address specific challenges or opportunities.

- **Define Objectives**: Clearly articulate the specific goals and objectives you want to achieve by implementing IIoT for real-time data collection and analysis [33]. These objectives should align with your organization's overall strategic vision and business priorities. Examples of objectives could include improving operational efficiency, enhancing product quality, optimizing maintenance schedules, reducing downtime, increasing safety, or achieving cost savings [34].
- **Identify Use Cases**: Identify and prioritize the specific use cases or scenarios where real-time data analysis can able to provide the maximum significant impact and value. Consider the areas within your industrial processes where real-time insights can drive actionable decisions, optimize performance, or mitigate risks. Examples of use cases could include predictive maintenance, real-time quality control, supply chain optimization, energy management, asset tracking, remote monitoring, or process optimization [35].

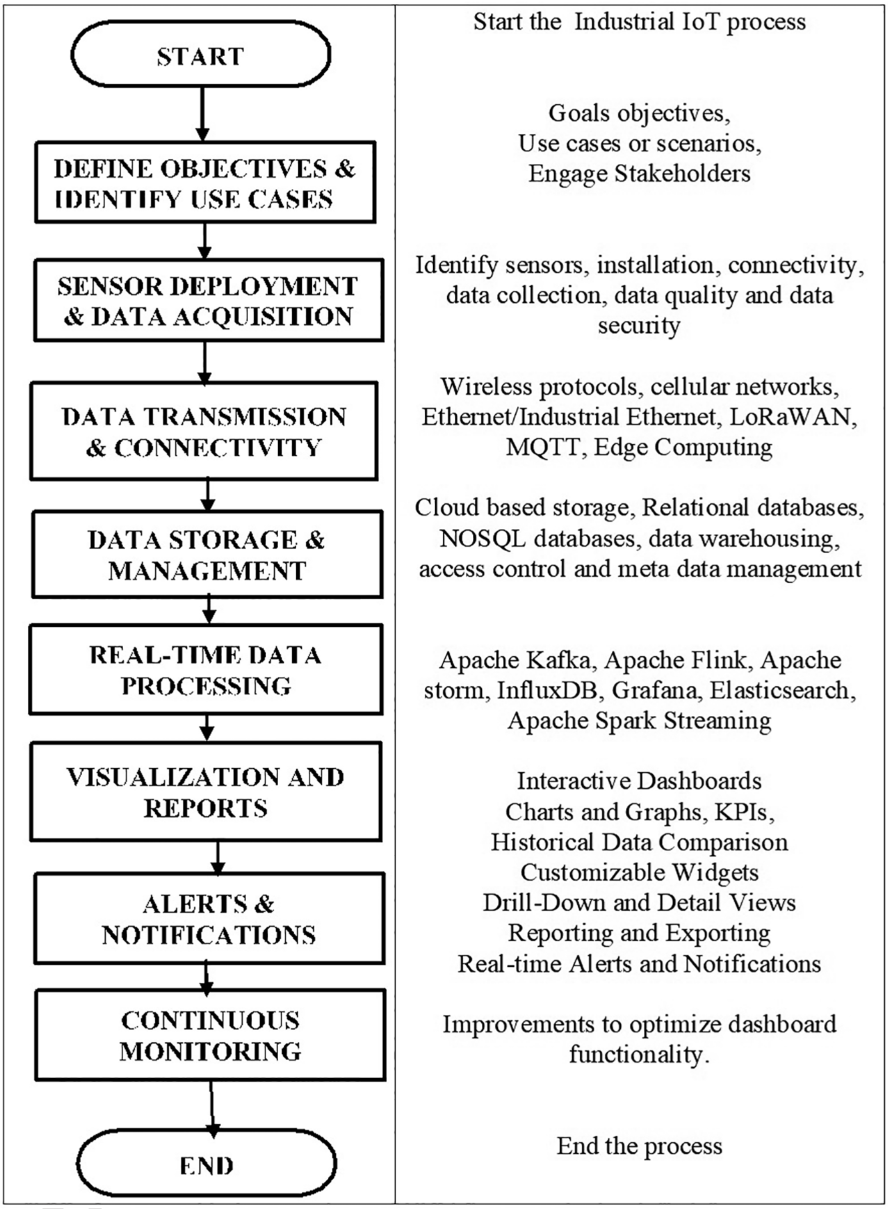

FIGURE 5.3 Flow chart and process note of IIoT dashboards.

- **Assess Feasibility and Impact**: Evaluate the feasibility and potential impact of each identified use case. Consider factors such as the availability of relevant data sources, technological capabilities, infrastructure requirements, resource allocation, and expected return on investment [36]. Prioritize the use cases based on their feasibility, potential benefits, and alignment with your defined objectives.

- **Set Specific and Measurable Goals**: Establish specific, measurable, achievable, relevant, and time-bound (SMART) goals for every identified use case. Define KPIs or metrics that will help track progress and measure the success of implementing IIoT real-time data collection and analysis and consider implications for big data analytics [37]. For example, if the objective is to improve operational efficiency, the goal could be to reduce downtime by 20% within 6 months.
- **Engage Stakeholders**: Involve relevant stakeholders from different departments or functions in the process of defining objectives and identifying use cases. Collaborate with operations teams, data analysts, subject matter experts, and decision-makers to gain insights, gather requirements, and ensure alignment with organizational goals. The Figure 5.4 shows the extended architecture of IIoT layers:

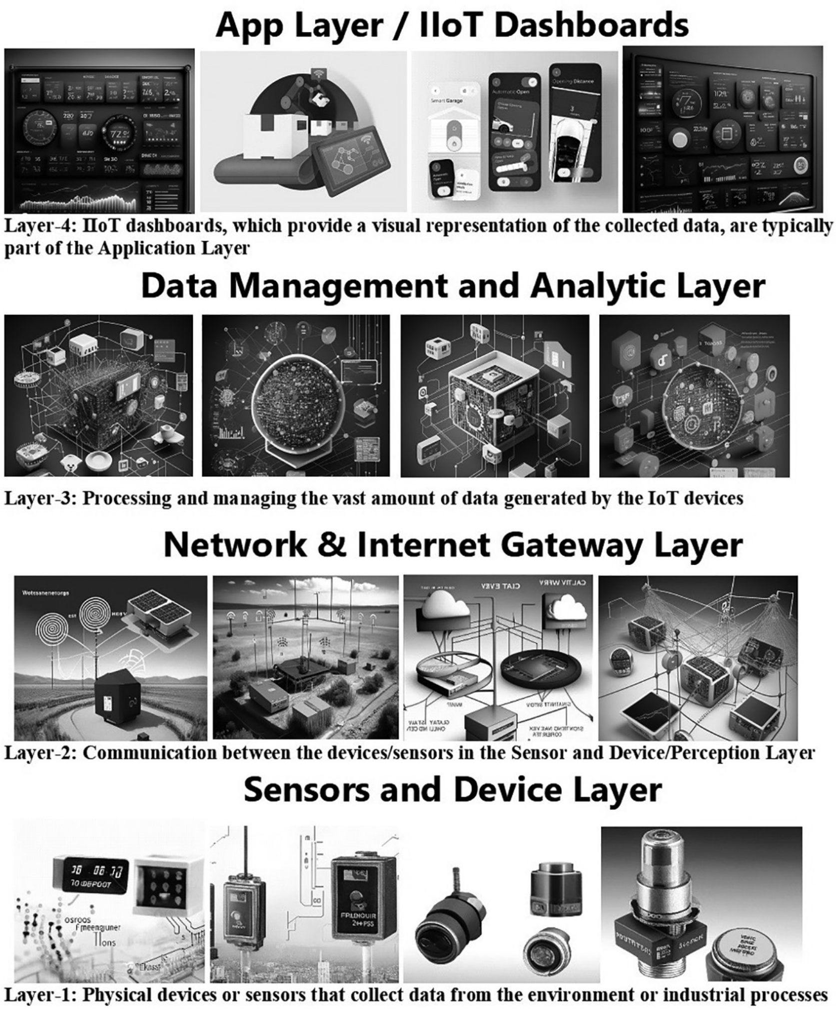

FIGURE 5.4 Layers and architecture of IIoT dashboard.

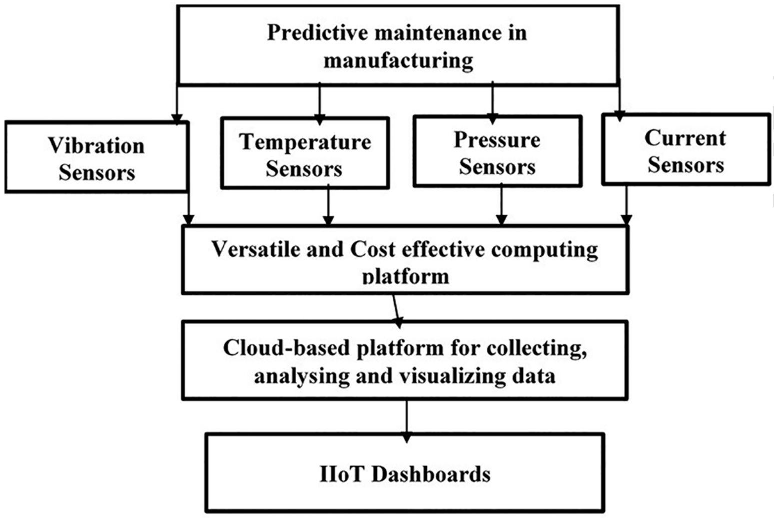

FIGURE 5.5 Block diagram: IIoT dashboard in manufacturing industry.

5.3.2 Unleashing the Power of Sensor Deployment and Data Acquisition in Real Time

Determine the appropriate sensors and devices needed to collect relevant data from industrial assets, machines, or processes. Install and configure the sensors to capture data in real-time and ensure proper connectivity to transmit the collected data.

Sensor deployment and data acquisition play a vital role in IIoT for real-time data collection and analysis. Here's an example of sensor deployment and data acquisition in IIoT for real-time data collection and analysis in manufacturing industry [38,39]:

The above block diagram in Figure 5.5 showcases the block diagram with the following use case in manufacturing industry to perform 'Predictive Maintenance' in manufacturing and primary objective to improve machine uptime and reduce unplanned downtime by implementing predictive maintenance techniques using real-time data [40].

Sensor Deployment and Data Acquisition Process:

- **Identify Critical Sensors**: Determine the specific sensors required to monitor the health and performance of manufacturing machines [41]. For example, vibration sensors, temperature sensors, pressure sensors, or current sensors.
- **Sensor Installation**: Install the identified sensors at strategic locations on the machines to capture relevant data [42]. For instance, place vibration sensors on rotating parts or temperature sensors near critical components.
- **Sensor Connectivity**: Establish connectivity options to ensure seamless data transmission from the sensors to the data storage or analysis platforms. This can be achieved through wired connections, wireless protocols (such as Wi-Fi or Bluetooth), or edge computing devices [42,43].
- **Data Collection and Transmission**: Configure the sensors to collect data at regular intervals or in real-time, depending on the specific requirements.

Enable the sensors to transmit the collected data to a centralized data storage system or cloud-based infrastructure securely [44].

- **Data Validation and Quality Assurance**: Implement data validation mechanisms to ensure the accuracy and reliability of the collected sensor data. Perform regular checks to identify and rectify any inconsistencies or anomalies in the data [45].
- **Time Synchronization**: Ensure that the sensors are synchronized to a common time reference to maintain accurate timestamps for the collected data. This enables proper alignment and correlation of data from different sensors [46].
- **Data Security**: Implement appropriate security measures to protect the sensor data from unauthorized access or tampering. Utilize encryption, access controls, and other security protocols to ensure data integrity and confidentiality [47].
- **Data Integration**: Integrate the sensor data with other relevant data sources, such as maintenance logs, operational data, or historical records, to gain a comprehensive view of the machine's health and performance [48].
- **Scalability Considerations**: Plan for scalability and flexibility in sensor deployment, allowing for easy expansion or reconfiguration as per changing needs or additional machines in the manufacturing environment [49].

By deploying sensors and acquiring data in this manner, manufacturers can continuously collect real-time data from machines, enabling predictive maintenance techniques. This real-time data collection and analysis help identify anomalies, detect early signs of machine failure, and trigger maintenance actions to prevent unplanned downtime and optimize overall equipment performance detailed in Figure 5.6 with Essential Elements of Streaming Sensor Data in IIoT [48–50].

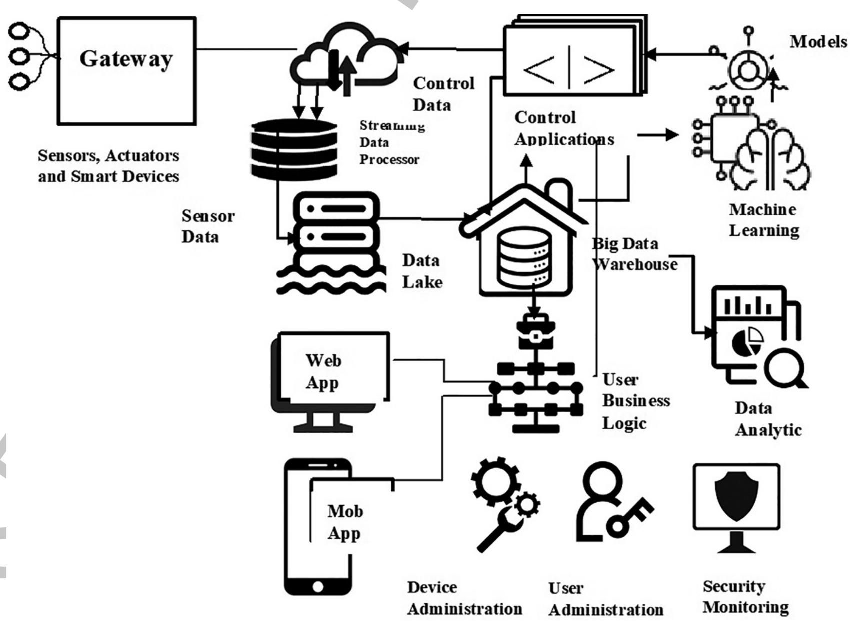

FIGURE 5.6 Essential elements of streaming sensor data in the IIoT.

5.3.3 Seamless Data Transmission and Connectivity in IIoT Landscape

Establish a robust and secure network infrastructure to enable seamless data transmission from the sensors to the data storage or analysis platforms [51]. Ensure reliable connectivity options, such as Wi-Fi, Ethernet, cellular networks, or even edge computing, depending on the specific requirements of the industrial environment [52].

In IIoT, various data transmission and connectivity technologies are utilized to ensure seamless communication between devices, sensors, and systems [53]. Some commonly used technologies in IIoT for data transmission and connectivity are shown in Table 5.5.

TABLE 5.5
IIoT Data Transmission Protocols and Technologies

Technology	Description
Wireless protocols (i) Wi-Fi	Enables high-speed wireless communication within a limited range, typically used for local area networking (LAN) applications.
Wireless protocols (ii) Bluetooth	Provides short-range wireless connectivity between devices, commonly used for low-power IoT devices and sensor networks.
Wireless protocols (ii) Zigbee	Designed for low-power, low-data-rate wireless communication over short distances, suitable for IoT applications with a large number of nodes.
Cellular networks 2G, 3G, 4G, and 5G:	Cellular networks offer wide-area coverage and provide reliable connectivity for IoT devices in remote or mobile applications. Each generation offers increased data rates, lower latency, and improved network capacity.
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Edge computing	Edge computing encompasses analyzing data at network edge which is quite nearer to the data source. It is an alternative to rely only on cloud-based servers. It reduces dormancy, advances decision-making and real-time monitoring process, and reduces bandwidth requirements.
Industrial ethernet protocols	Specific industrial Ethernet protocols, such as Modbus TCP/IP, PROFINET, and EtherNet/IP, are widely used in industrial automation and control systems to enable real-time data exchange and communication between devices and machines.

It is essential to consider that the choice of data transmission and connectivity technology depends on various factors, including the specific use case, communication range, data volume, power consumption requirements, security considerations, and available infrastructure. A combination of these technologies may be used in complex IIoT deployments to ensure reliable and efficient data transmission in industrial settings and novel edge architecture for AI-IoT services deployment [54].

5.3.4 Effective Data Storage and Management Strategies for Real-Time Insights

Set up a centralized data storage system or cloud-based infrastructure to securely store the collected real-time data. Implement data management practices, including data cleaning, pre-processing, and data integration from various sources, to ensure data quality and consistency [55].

In IIoT, effective data storage and management are essential for handling the large volumes of data generated by connected devices, sensors, and systems and load-optimized sensor data store for IIoT gateways [56]. Table 5.6 shows detailed key aspects of data storage and management in IIoT.

TABLE 5.6
Key aspects of Data Storage and Management in IIoT

Purpose	Technologies
Data storage infrastructure (Cloud-based storage)	Utilizing cloud platforms such as AWS - Amazon Web Services, Google Cloud Platform or Microsoft Azure, allows for scalable, flexible, and reliable data storage. Cloud storage offers high availability, data redundancy, and easy accessibility from anywhere [57].
Data storage infrastructure (On-premises storage)	Some organizations prefer to maintain their data storage infrastructure on-premises to have complete control over data security, compliance, and latency. This typically involves deploying dedicated servers, storage systems, or data centers [58]
Database Systems (Relational Databases)	Traditional RDBMS - relational database management systems like Oracle, Microsoft SQL Server or MySQL are commonly used for structured data storage in IIoT. They provide ACID (Atomicity, Consistency, Isolation, Durability) compliance and support complex querying capabilities [59].
Database systems (NoSQL databases)	Non-relational databases such as MongoDB, Cassandra, or Apache HBase are suitable for storing unstructured or semi-structured data generated by IIoT devices. NoSQL databases offer scalability, flexibility, and fast data ingestion [59]

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TABLE 5.6 (*Continued*)
Key aspects of Data Storage and Management in IIoT

Purpose	Technologies
Time-series data storage	Time-series databases like InfluxDB, Prometheus, or Graphite are designed specifically to handle large volumes of time-stamped data generated by sensors and devices in IIoT applications. They provide efficient storage, retrieval, and analysis of time-series data [60].
Data integration and aggregation (Data integration platforms)	Integration platforms such as Apache Kafka, MQTT brokers, or enterprise service buses (ESBs) enable seamless data aggregation and consolidation from various sources in IIoT deployments. They ensure efficient data flow between connected devices, systems, and applications [61].
Data integration and aggregation (Data warehousing)	Data warehousing solutions like Apache Hadoop, Snowflake, or Google BigQuery enable centralized storage and integration of data from multiple sources, facilitating comprehensive analytics and reporting [62].
Data security and compliance (Data encryption)	Implement encryption techniques to safeguard secured data both in transit and at rest. Encryption safeguards that information remains secure and unreadable to unauthorized parties [63].
Data security and compliance (Access controls)	Utilize role-based access controls (RBAC) and authentication mechanisms to manage data access permissions and ensure data privacy and confidentiality [64]
Data security and compliance(Compliance measures)	Adhere to industry-specific regulations (e.g., GDPR, HIPAA) and implement necessary compliance measures to safeguard data integrity, privacy, and regulatory requirements.
Data lifecycle management(Data retention policies)	Define policies for data retention and archiving based on regulatory requirements, business needs, and data analysis purposes. This ensures efficient storage utilization and compliance [65].
Data lifecycle management(Data backup and recovery)	Implement regular backup procedures to protect against data loss or system failures. Having robust backup and recovery mechanisms is crucial for data resilience and business continuity.
Data governance and metadata management	Data Governance Frameworks: Establish data governance frameworks to define policies, standards, and procedures for data management, quality assurance, and data lifecycle governance.
Metadata management	Maintain metadata repositories to catalog and manage data attributes, data lineage, and data relationships, aiding data discovery and understanding.

Effective data storage and management practices in IIoT ensure the availability, reliability, security, and accessibility of data for real-time analysis, decision-making, and business insights. These practices enable organizations to maximize the potential of their IIoT deployments and derive meaningful value from the collected data. Securing the integrity of big data in IIoT for smart manufacturing is a rapidly expanding and promising area with a futuristic outlook [66].

5.3.5 Real-Time Data Processing and Analysis: Transforming Data into Actionable Insights

To handle incoming real-time data with minimal delay, it is crucial to employ suitable data processing techniques like stream processing or edge computing [67]. These techniques enable the extraction of valuable insights, identification of patterns, anomalies, or predictive trends through the application of analytics algorithms, machine learning models, or statistical techniques [68,69].

Real-time data processing and analysis within IIoT dashboards provide continuous monitoring, analysis, and decision-making capabilities based on the most up-to-date information. This empowers organizations to optimize operations, improve efficiency, detect anomalies, and proactively address issues, leading to enhanced business outcomes in industrial settings [70].

Real-time data processing and analysis in IIoT dashboards rely on a variety of technologies that address the challenges of real-time data ingestion, processing, and visualization [71]. Some key technologies used in this context listed in Table 5.7.

Some of the following technologies listed in Table 5.8 are widely used in the big data and real-time data processing domains and offer different capabilities for handling streaming data, storing and analyzing time series data, and creating visualizations and dashboards [72].

TABLE 5.7
Technologies for Real-Time Data Processing and Analysis IIoT Dashboards

Technology	Applications
Stream processing	Enables the processing of data in motion, allowing for real-time analysis and decision-making.
Edge computing	Brings data processing capabilities closer to the source, reducing latency and enabling real-time insights at the edge of the network.
Analytics algorithms	Algorithms designed to analyze and extract valuable information from real-time data streams.
Machine learning models	Utilized to detect patterns, anomalies, or predict trends within the real-time data, enabling proactive decision-making.
Statistical techniques	Employed to analyze and interpret real-time data, providing valuable insights and supporting informed decision-making.

TABLE 5.8
Big Data and Real-Time Data Processing Domains in IIoT Dashboards

Technology	Applications
Apache kafka	Kafka [73] is a distributed streaming platform that allows for real-time data ingestion and processing. It enables the collection, storage, and processing of high-volume, high-throughput data streams from multiple sources, making it suitable for real-time data pipelines in IIoT applications.
Apache flink	Flink is a powerful stream processing framework that supports real-time data processing, event time processing, and stateful computations. It provides capabilities for windowing, time-based aggregations, and complex event processing, making it well-suited for real-time analytics in IIoT dashboards [74].
Apache storm	Storm is a distributed stream processing system that enables real-time processing of high-velocity data streams. It provides fault tolerance, scalability, and low-latency processing, making it suitable for real-time analytics and event processing in IIoT applications [75].
InfluxDB	InfluxDB is a time-series database designed for handling large volumes of time-stamped data, making it ideal for storing and retrieving real-time data in IIoT dashboards. It offers high-performance queries, efficient data compression, and retention policies, allowing for real-time analytics and visualization [76].
Grafana	Grafana is an open-source data visualization and monitoring platform that integrates with various data sources, including time-series databases like InfluxDB. It provides customizable dashboards, real-time streaming updates, and a wide range of visualization options, making it popular for visualizing real-time data in IIoT applications [77].
Elasticsearch	Elasticsearch is a distributed search and analytics engine that can be used for real-time data indexing, search, and analysis. It offers near real-time indexing and querying capabilities, making it suitable for storing and retrieving real-time data in IIoT dashboards [78].
Apache spark streaming	Spark Streaming is a real-time stream processing framework that is part of the Apache Spark ecosystem [79]. It provides scalable and fault-tolerant stream processing capabilities, enabling real-time data ingestion, transformation, and analytics in IIoT applications.

These technologies, along with others, provide the necessary tools and frameworks to handle the complexities of real-time data processing and analysis in IIoT dashboards. They enable organizations to extract valuable insights, make informed decisions, and drive real-time actions based on the continuously evolving data from industrial processes and systems.

5.3.6 Visualizing and Reporting Real-Time Insights with Impactful Dashboards

Develop interactive and user-friendly dashboards or visualization tools to present real-time data and analysis results in a comprehensible format. Enable stakeholders, decision-makers, and operators to access and interpret the real-time data through intuitive visualizations, charts, and reports. Visualization and reporting in IIoT dashboards play a critical role in presenting real-time data in a meaningful and easily understandable format [80]. Here are some approaches and techniques for visualization and reporting in IIoT dashboards listed in Table 5.9.

TABLE 5.9
Approaches and Techniques for Visualization and Reporting in IIoT Dashboards

Type	Applications
Interactive dashboards	IIoT dashboards provide interactive visualizations that allow users to explore and interact with the data. Users can zoom in/out, filter data based on criteria, and dynamically adjust the time range to focus on specific periods of interest [81].
Real-time data updates	IIoT dashboards display real-time data updates, ensuring that the visualizations reflect the most current information from the connected devices, sensors, and systems. Real-time updates enable users to monitor changing conditions and make timely decisions [82].
Charts and Graphs	Dashboards often include various types of charts and graphs such as line charts, bar charts, pie charts, scatter plots, and heatmaps. These visual representations allow users to quickly grasp trends, patterns, and correlations in the data [83].
Key performance indicators (KPIs)	IIoT dashboards prominently display key performance indicators relevant to industrial processes. KPIs can include metrics such as machine performance, production rates, energy consumption, quality indicators, and equipment downtime. Clear visual indicators such as gauges, meters, or progress bars help users monitor and track performance against targets [84].
Historical data comparison	IIoT dashboards often provide the capability to compare current real-time data with historical trends and patterns. This allows users to identify anomalies, deviations, or changes in behavior, providing valuable insights for decision-making [85].
Customizable widgets	Dashboards offer customizable widgets that allow users to configure their own views based on their specific needs. Users can select relevant metrics, create personalized visualizations, and arrange the widgets according to their preferences [86].
Drill-down and detail views	IIoT dashboards enable drill-down capabilities to explore more detailed information. Users can click on specific data points or regions of interest to view more granular data, supporting deeper analysis and troubleshooting [87].

(*Continued*)

TABLE 5.9 (*Continued*)
Approaches and Techniques for Visualization and Reporting in IIoT Dashboards

Type	Applications
Reporting and exporting	IIoT dashboards often include reporting features that allow users to generate and export reports in various formats such as PDF, Excel, or CSV. Reports can summarize key metrics, trends, and insights for sharing with stakeholders or for further analysis [88].
Real-time alerts and notifications	Dashboards can be configured to generate real-time alerts and notifications based on predefined thresholds or critical events. Users can receive alerts via email, SMS, or in-app notifications, ensuring timely response and intervention [89].

Visualization and reporting in IIoT dashboards enhance situational awareness, enable data-driven decision-making, and support performance monitoring in industrial settings. These features empower users to derive insights, identify issues, and take proactive actions based on the real-time data visualizations and reports provided by the dashboards [90].

5.3.7 Instant Alerts and Notifications: Staying Ahead in the Age of IIoT

Implement alert mechanisms and notification systems to trigger immediate actions or alerts based on predefined thresholds, anomalies, or critical events detected from the real-time data. Configure real-time alerts to notify relevant personnel or systems to take proactive measures or initiate automated responses when necessary.

5.3.8 Continuous Monitoring and Optimization: Maximizing Efficiency in Real Time

Establish a feedback loop to continuously monitor and evaluate the effectiveness of the IIoT-enabled real-time data collection and analysis system. Regularly assess the performance, accuracy, and efficiency of the system and make necessary adjustments or improvements to optimize its functionality.

5.4 ENHANCING OPERATIONAL VISIBILITY AND BEST PRACTICES: IMPLEMENTING SUCCESSFUL IIoT DASHBOARDS

Enhancing operational visibility involves leveraging IIoT dashboards to improve understanding and insight into various aspects of industrial operations such as machinery-related faults and energy conception-related faults. This is achieved by capturing and visualizing real-time data from connected devices, sensors, and systems, enabling data-driven decision-making that optimizes performance and drives operational excellence [91].

Data-driven decision-making with IIoT dashboards entails utilizing real-time data collected from industrial processes to gain insights, identify patterns, and make informed decisions [92] for e.g. based on the patterns and insights the business owner can decide about starting or shutting down the plant in a long run. By visualizing this data through intuitive and interactive dashboards, decision-makers can monitor KPIs, track operational metrics, and assess the overall health of their industrial operations [93].

An example of enhancing operational visibility and data-driven decision-making with IIoT dashboards can be observed in the manufacturing industry, specifically in a large automotive manufacturing plant [94,95].

In this industry, IIoT sensors are deployed throughout the production line to capture real-time data on various parameters such as machine performance, equipment health, energy consumption, and quality metrics. This data is transmitted and collected in a centralized IIoT platform, which feeds into a comprehensive dashboard [96].

The IIoT dashboard provides a visual representation of specific KPIs related to the manufacturing process [97]. For example, it displays real-time data on production rates, machine utilization, downtime, and quality metrics like defect rates or rework percentages.

By monitoring these metrics in real time, plant managers and operators gain immediate visibility into the performance and health of the production line. They can identify bottlenecks, diagnose issues, and take proactive measures to optimize operations. For instance, if a machine's performance starts to decline, the dashboard triggers an alert, notifying the responsible personnel to address the issue promptly [98].

The dashboard also enables data analysis and visualization, allowing stakeholders to identify trends, patterns, and correlations. They can track the impact of process changes, evaluate the effectiveness of improvement initiatives, and make data-driven decisions to enhance productivity and quality [98].

Moreover, the IIoT dashboard can support predictive analytics capabilities. By analyzing historical and real-time data, the dashboard can generate predictive models to forecast potential machine failures, optimize maintenance schedules, and minimize downtime [99].

Overall, in the manufacturing industry, the use of IIoT dashboards enhances operational visibility, empowers data-driven decision-making, and enables proactive measures to optimize production, reduce costs, and improve product quality [99,100].

5.4.1 Revolutionizing Crude Oil Production with IIoT and Edge Computing

Ramzey et al. present a framework that leverages IIoT and Edge Computing technologies to enhance operational visibility and enable data-driven decision-making in the crude oil production industry [101].

The framework aims to address the challenges faced in real-time monitoring and controlling of crude oil production processes by utilizing the capabilities of IIoT and

Edge Computing. It establishes a smart monitoring system that collects and analyzes real-time data from various sensors and devices deployed in the production environment [101].

Key points and useful information extracted from the article include:

- **Objective**: The framework's primary objective is to enable real-time monitoring and control of crude oil production processes, allowing operators to make data-driven decisions and optimize production efficiency.
- **IIoT Integration Process**: The framework integrates IIoT technologies, leveraging sensor data, network connectivity, and cloud computing to collect and transmit real-time data from the production site to a centralized system.
- **Edge Computing**: Edge computing is utilized to perform data processing and analysis tasks at the edge of the network, closer to the data source, enabling faster response times and reducing the dependence on cloud infrastructure.
- **Real-Time Monitoring**: The current framework enables real-time monitoring of crucial parameters such as oil flow rate, temperature, pressure, and equipment status. This information is visualized through an IIoT dashboard, providing operators with a comprehensive view of the production process.
- **Data Analytics**: The collected data is analyzed using advanced analytics techniques, including data analytic and machine learning algorithms, to identify patterns, anomalies, and predictive insights. This analysis aids in optimizing production, detecting equipment failures, and enabling predictive maintenance.
- **Decision-Making**: The framework supports data-driven decision-making by providing dashboard operators with actionable insights derived from the real-time data. This empowers them to take proactive measures, optimize production processes, and minimize downtime.
- **Benefits**: The implementation of the above framework offers several benefits, including enhanced operational visibility, improved production efficiency, reduced downtime, optimized maintenance, and cost savings.

The article showcases the significance of leveraging IIoT and Edge Computing technologies in the crude oil production industry. By adopting the I2OT-EC framework, companies can achieve real-time monitoring, data-driven decision-making, and ultimately optimize their crude oil production processes [101].

5.4.2 Revolutionizing Agriculture: IoT-Enabled Smart Agri Dashboards

Kayetha and Pabboju discuss the development of an IoT-based smart device for agricultural purposes [102]. Here are some useful pieces of information related to enhancing operational visibility and data-driven decision-making with IIoT dashboards:

- **Objective**: The principal goal of the proposed work is to produce a connection between farmers and farms by developing an IoT-based system and smart device that collects and stores sensor-based data to repossess water and soil parameters. The device also provides crop recommendations based on the collected/stored data.

- **Methodology**: Internet of Things (IoT) system, sensor networks, big data, data mining, machine learning algorithms. Components such as Raspberry Pi, Sensors like DHT11 (Digital humidity and temperature sensor), soil moisture, LDR (Light Dependent Resistor sensor), ultrasonic sensor, NPK (Nitrogen, Phosphorus, and Potassium sensor), pH sensor, and others are used to collect data related to soil properties and weather conditions.
- **Crop Prediction**: The prediction module contains Gaussian Naive Bayes algorithm to predict suitable/appropriate crops based on parameters such as pH, N, P, K, humidity, temperature, and rainfall. The model for crop prediction is trained using a dataset from the Kaggle database.
- **Comparison with Traditional Methods**: The proposed system is compared to existing outdated methods such as laboratory-based soil testing. The traditional methods involve very lengthy and expensive policies and procedures for soil testing and as well as for crop prediction. In contrast, this proposed IoT-based dashboard system provides faster results at a lesser cost and makes instant digital data obtainable on a cloud-server.
- **Efficiency and Accuracy**: This system demonstrates efficient performance with a 99.3% accuracy rate with comparison to a previous accuracy of 97.18%. The system allows a single device for multiple soil tests, and the other advantage is the instant result viewing feature, eliminating the need for time-consuming lab-based testing.
- **Novelty**: The proposed system differs from existing systems by using Raspberry Pi (small, affordable single board computer) used for soil tests. This also supports high-end sensors and is companionable with the advanced and recent machine-level algorithms. It also uses an NPK sensor to directly measure the nutrient values instead of using a soil electrical conductivity sensor and color sensor, making the process more efficient.
- **Integration with IoT Dashboards**: The data collected from sensors is stored in the ThingSpeak cloud server, which enables monitoring of crop conditions. The data can be visualized and analyzed using IoT dashboards, providing operational visibility and facilitating data-driven decision-making.

Overall, the article highlights the use of IoT dashboards and data-driven approaches in agriculture to enhance operational visibility and enable stakeholders to make informed decisions based on real-time data [102,103].

5.5 CONCLUSION

Transforming Industry 5.0: Real-Time Monitoring and Decision-Making with IIoT dashboards have highlighted the significant impact of real-time monitoring and decision-making process enabled by IIoT in shaping the future of industries. Throughout this chapter, we have explored the various applications, benefits, and challenges associated with implementing IIoT technologies.

Enhancing operational visibility through IIoT dashboards is a powerful strategy for industries to improve understanding, optimize performance, and drive operational excellence. By capturing and visualizing real-time data from connected devices, sensors, and systems, decision-makers can gain insights, monitor KPIs, and assess the overall health of industrial operations. The application of IIoT dashboards in manufacturing plants and the crude oil production industry demonstrates their effectiveness in identifying issues, optimizing processes, and enabling data-driven decision-making. Similarly, in agriculture, IoT-enabled smart agriculture dashboards empower farmers to collect and analyze sensor-based data, predict suitable crop types, and make informed decisions for optimized farming practices. However, along with the opportunities, challenges have also emerged in this new era of Industry 5.0. The complete volume and complexity of raw data produced by IIoT channels/devices pose challenges in terms of data management, storage, and security. Ensuring the privacy and security of sensitive data has become a crucial concern for industries. Additionally, the integration of legacy systems with IIoT technologies and the need for skilled professionals proficient in IIoT implementation present further challenges [104].

Looking into the near future, it is evident that IIoT will endure to play a pivotal role in transforming industries in sustainable way. We can anticipate several interesting future trends that will shape the landscape of Industry 5.0. First, recent advancements in artificial intelligence and edge computing will enable faster and more accurate process monitoring, real-time decision-making, empowering industries to respond swiftly to changing conditions. Second, the convergence of IIoT with other emerging technologies such as block chain, robotics, and 5G will unlock new possibilities, creating intelligent and interconnected ecosystems. Moreover, addressing the challenges associated with IIoT implementation will be crucial. Industry leaders and stakeholders must invest in robust cybersecurity measures to protect sensitive data and build trust in the ecosystem and to improve the data integrity. Efforts should also focus on upskilling the workforce to bridge the skills gap and enable seamless integration of IIoT technologies into existing systems.

In conclusion, the transformative potential of real-time monitoring and decision-making with IIoT is immense. By embracing these technologies, industries can unlock new levels of efficiency, productivity, and competitiveness with above evidences of several industries such as oil industry and agriculture. However, it is essential to navigate the challenges and proactively adapt to the evolving trends to fully harness the benefits of IIoT and drive the future of Industry 5.0.

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