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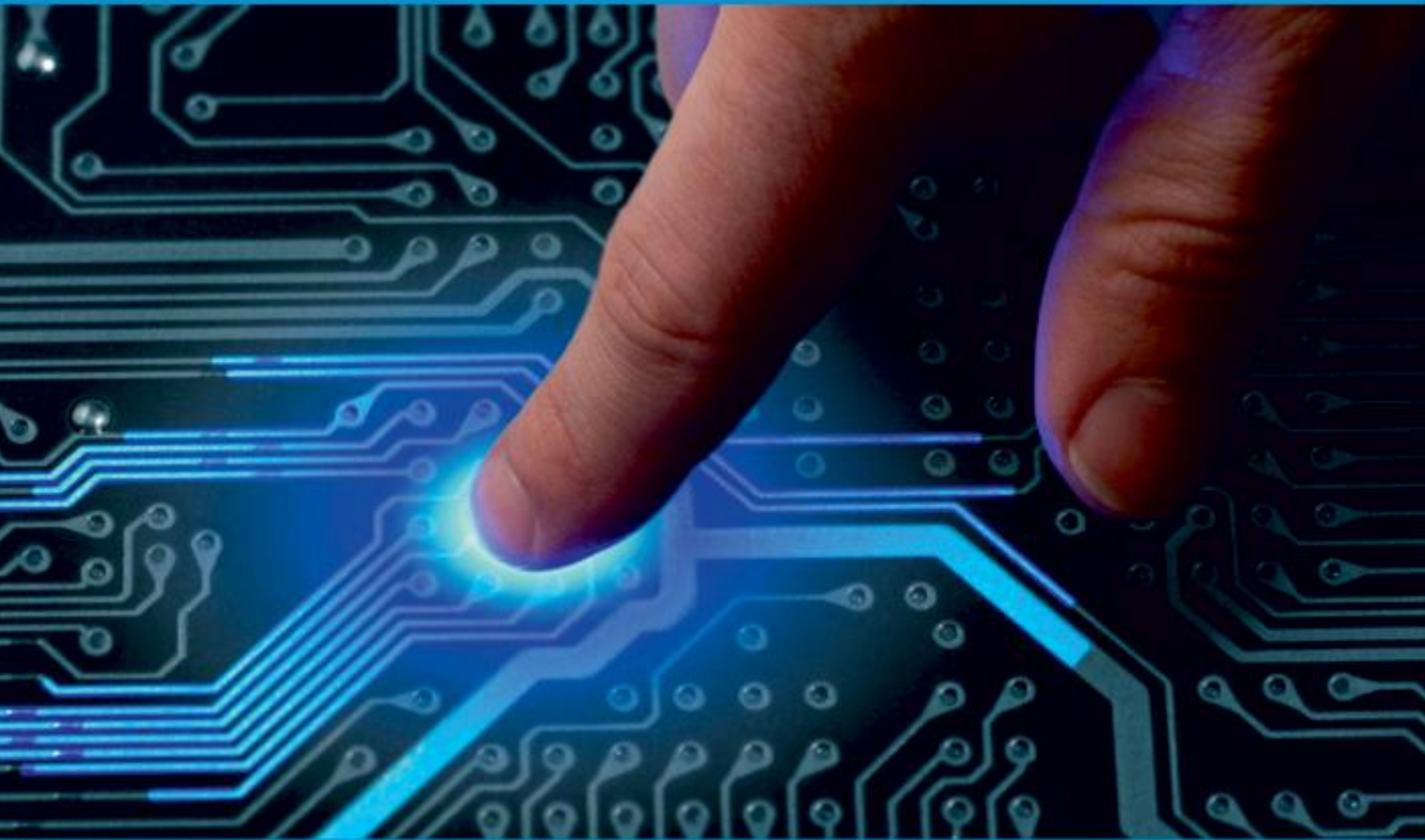

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Industrial Internet of Things –IIoT

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ABSTRACT: The Industrial Internet of Things (IIoT) is a rapidly growing field that involves connecting industrial machines, equipment, and devices to the internet and other networks. This connectivity allows for the collection and analysis of large amounts of data from sensors and other sources, leading to greater efficiency, productivity, and cost savings in industrial operations.

The IIoT is characterized by the use of advanced sensors, actuators, and other devices that can communicate with each other and with central systems, such as cloud platforms, to exchange data and perform complex tasks. This technology is being used in a variety of industries, including manufacturing, energy, transportation, and healthcare, among others.

One of the key benefits of the IIoT is the ability to monitor and control industrial processes in real-time, allowing for quick identification and response to potential problems or inefficiencies. This can lead to improved safety, reduced downtime, and increased quality and consistency of output.

However, the IIoT also presents challenges related to data privacy and security, as well as the need for specialized skills and expertise in areas such as data analytics and cybersecurity. As the IIoT continues to grow and evolve, it is expected to have a significant impact on the way industrial operations are managed and optimized.

KEYWORDS: A network of connected devices in the industry, transfer data without human-to-human or human-to-computer interaction etc.

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I. INTRODUCTION

The development of wireless technologies during the past decades has led to a novel paradigm called the Internet of Things termed as IoT. The IoT paradigm was firstly introduced by Kevin Ashton in 1998 as a concept for connecting things or objects to the Internet. Although IoT is believed to have a wide range of benefits in many IoT applications such as smart homes, healthcare, transportation and environment, it is also believed to have a significant impact in the industry by achieving more efficient, optimized monitoring and controlling with reduce cost. IoT is expected to bring innovations and benefits to the industry leading to the concept of IIoT. The IIoT system allows the industry to collect and analyze a large amount of data that can be used to improve the overall performance of industrial systems, providing various types of services. The IIoT system is also believed to bring cost reduction in Capital Expenditures and Operating Expenses .Many similar terms are coined to describe the concept of IoT into Industry, for example, Industry 4.0, Industrial IoT and Smart Manufacturing etc. The core concept behind all these terms is the use of advanced technologies and applications (e.g. IoT, 5G, Cloud computing, Edge/Fog computing, Machine learning etc.) specially optimized for industrial processes.

In 2011, an initiative led by the German government, called "Industry 4.0" or sometimes refer as "Industrie 4.0", was introduced in order to improve the efficiency of manufacturing in industry. aims to exchange and collect information during the whole lifecycle of any product.We define the IIoT as: Industrial IoT (IIoT) is the network of intel ligent and highly connectedindustrial components that are deployed to achieve high production rate with reduced operationalcosts through real-time monitoring, efficient management and controlling of industrial processes,assets and operational time.IIoT is a subset of IoT which requires higher levels of safety, security and reliable communication without thedisruption of real-time industrial operations due to mission-critical industrial environments. The focus of IIoT isefficient management of industrial assets and operations along with predictive maintenance. Table 1 outlines the keydifferences among IoT and IIoT systems. On the other hand, Industry 4.0 is a subset of IIoT which focuses on safetyand efficiency in manufacturing. The evolution of IIoT is expected widely in future industrial networks as well.

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TheIIoT will enable Industry 5.0 systems to narrow the gap between human and machines and it will help to achievemassive personalization vision of Industry 6.0. However, considering currency technology ecosystem, we limited ourdiscussions to IIoT

Table 1.1: Operational Difference Between IoT and IIoT Systems

Concentration	**IIoT**	**IoT**
Area of Focus	Industrial Applications	General Applications
Focus Development	Industrial Systems	Smart Devices
Security and Risk Measures	Advanced and Robust	Utility-centric
Interoperability	CPS-Integrated	Autonomous
Scalability	Large-scale Networks	Low-scale Network
Precision and Accuracy	Synchronized with milliseconds	Critically Monitored
Programmablity	Remote on-site programming	Easy Off-site programming
Output	Operational Efficiency	Convenience and Utilization
Resilience	High Fault Tolerance Required	Not Required
Maintenance	Scheduled and Planned	Consumer Preferred

II. IIoT: STATE-OF-THE-ART RESEARCH EFFORTS

2.1 IIoT Architectures and Frameworks

A generic architecture of IIoT systems was discussed by industrial internet consortium [11] which is presented in Figure 2 where by IIoT devices and industrial data sources generate continuous data streams at Layer-1 while the edge servers and cloud computing systems empower IIoT applications at Layer-2 and Layer-3, respectively. The enterprise applications are depicted at Layer-4. Figure 2 also shows the flow of data and information among different layers as well as it exhibits the orchestration flow for resource management and operational flow for managing assets in the industrial networks. However, different researchers perceive these architectures differently considering design variations in terms of location awareness, communication paradigms, computational assignments, execution paradigms, resource management schemes, safety, security, privacy, addressability, and resilience, to name a few. Table 4 shows the main features of IIoT architectures. The details of these architectures is given as follow.

G. Campobello *et al.* [12] have proposed a solution for IIoT named Wireless EVolution for Automation (WEVA) that is based on open source software and communication protocols. Its architecture consists of sensors, actuator boards, motes and operating system, protocols, access gateway, services, and applications. Moreover, WEVA uses Easy WSN as a graphical management tool. The authors suggest that IPv6 is a requirement for IIoT in terms of flexibility. However, incorporating these network technologies is not an easy job in order to achieve a high-performance IIoT in terms of (latency, security etc.). Many researchers have proposed solutions however, they address a specific performance issue and ignore the integration of Wireless Sensors Network (WSN) which plays important role in industrial applications.

C. K. M. Lee *et al.* [13] have proposed an IIoT suite to achieve re-industrialization for Hong Kong by addressing various challenges like objects identification in real-time and their locations throughout the manufacturing processes, establish a network system that allows objects to communicate between the network and other objects in real time etc. The main components of the IIoT suite architecture include a smart hub and a cloud platform.

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IIoT	Industrial Internet of Things
CPS	Cyber Physcial Systems
IAM	Identification and Access Management
PMR	Physical Manufacturing Resource
CoAP	Constrained Application Protocol
LPS	Local Pool Service
ASN	Absolute Slot Number
TT	Timeslot Template
MQTT	Message Queue Telemetry Transport
RTT	Round Trip Time
DML	Data Management Layer
LM	Local Manager
CCM	Concentric Computing Model
H2M	Humane-to-Machine
M2M	Machine-to-Machine
TPSN	Timing-sync Protocol for Sensor Networks
GPA	Groupwise Pair selection Algorithm
STETS	Spanning Tree-based Energy-efficient Time Synchronization
PCA	Prioritized Contention Access
CSMA/CA	Carrier-sense Multiple Access with Collision Avoidance

Table 2.1: Abbreviations used in this study.

to accomplish three tasks. First, it facilitates the communication, data exchange and data processing between IoT devices. Second, it provides convenient solutions when scaling the system with new IoT devices. Finally, it provides a secure connection channel between IoT devices and the cloud platform by performing data collection, filtering, aggression, and formatting. The cloud platform of IIoT acts like the brain of the IIoT suite, and is responsible for performing Identification and Access Management (IAM), load balancing, device discovery/configuration, routing algorithm, monitoring and controlling IoT devices.

object, gateway, and control center. Each module performs special functionality and is consisting of three layers which include an application layer, network layer and a sensing layer. Smart objects are installed on different oil and gas equipment (e.g. pipelines, storage tanks, pumps and wellheads etc.). These smart objects are equipped with different types of sensors (flow, pressure, temperature and acoustic etc.) to detect different events like leaks, fire and fluid level etc. Smart objects send their sensed data directly or through gateway to the control center. Smart objects and gateways are also equipped with radio transceiver (short and long range). The control center consists of databases for data storage, management applications, smart object interfaces, data analysis and data visualization tools.

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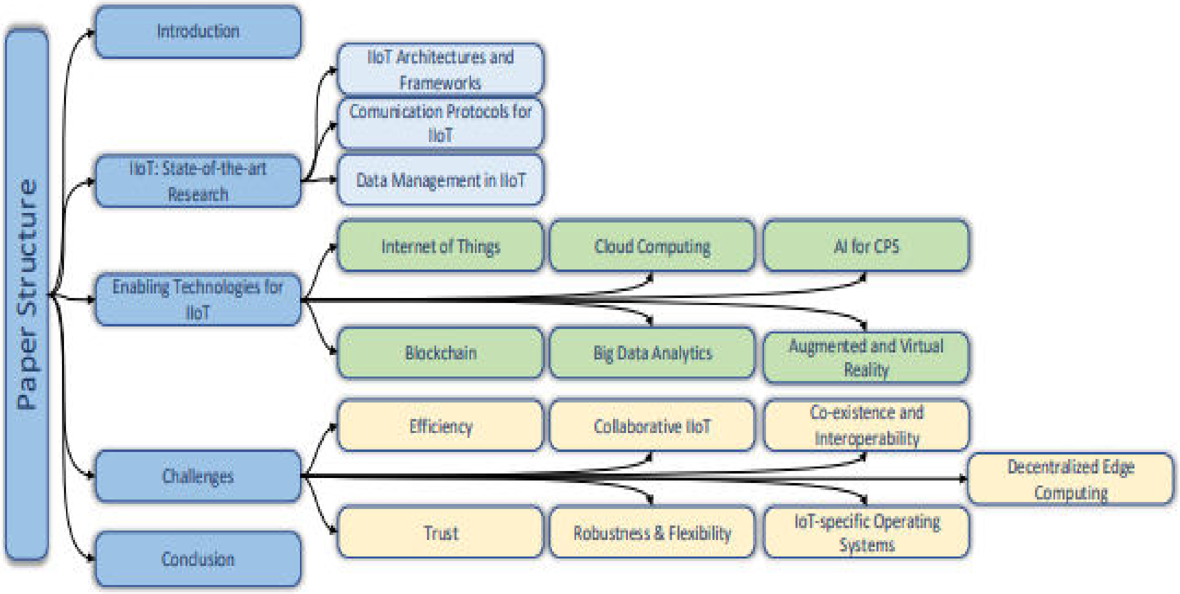

Fig-2.2: Paper Structure

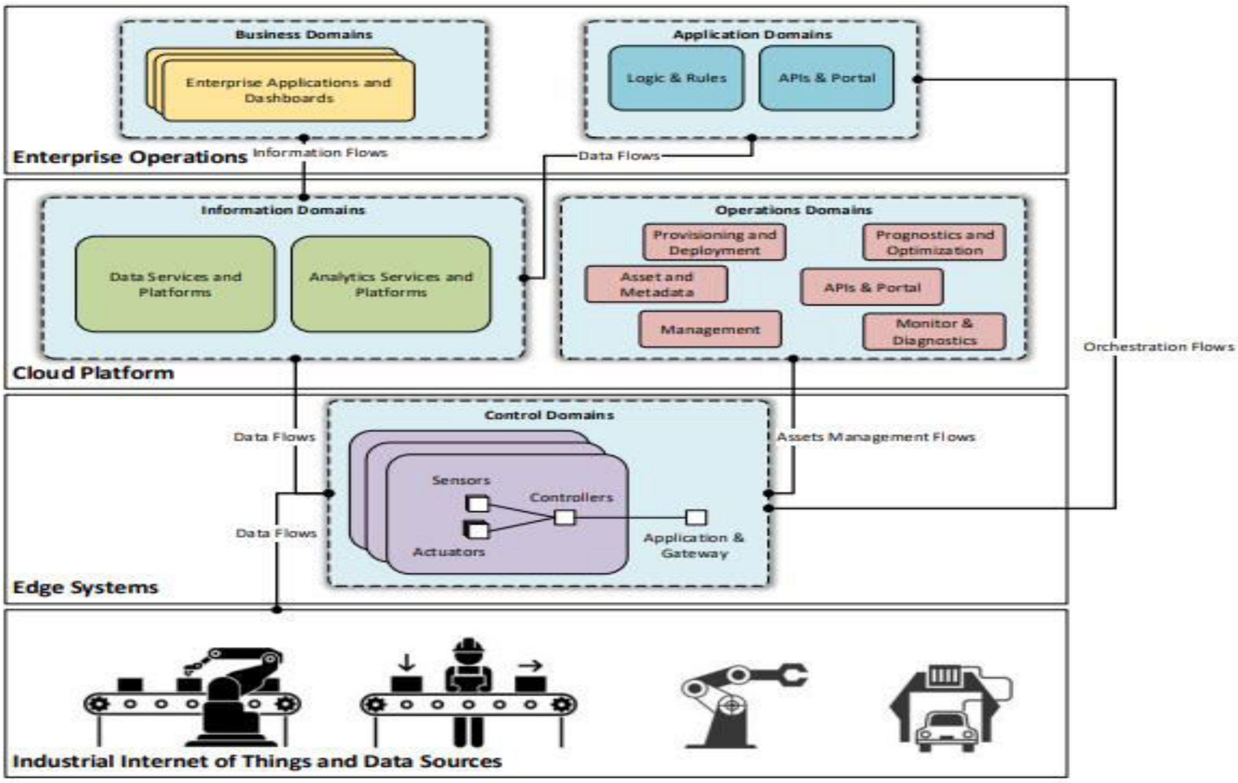

Fig 2.3 : A general architecture for IIOT systems

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The deployment, configuration, and interaction between heterogeneous IIoT devices are an important issue. To cope with these issues, F. Tao *et al.* [15] have proposed an IIoT based hub called IIHub. The IIHub consists of three modules. The first module is called Customized Access Module (CA-Module) which is responsible for connectingheterogeneous devices called PMRs (Physical Manufacturing Resources) through a group of communication protocols.
The second module is called A-Hub (Access Hub) which works as a bridge between factory worker, smart terminals and CA-Module through Wifi or Ethernet interfaces and Constrained Application protocol. The third and most important module is called LPS (Local Pool Service) or smart terminals. LPS perform their different functions and are responsible for data collection, processing, smart decision making and storing. Based on data generated by PMRs, LPS perform real-time data processing and predict expected production rate, total energy consumption and PMRs predicted maintenance. Each IIHub module is embedded with special purpose libraries. CA-Module has a group of communication protocols which interact with each other using a library called CPPLib (Communication Protocol Package Library).
A-Hub has an embedded library called MDIMLib (Multi-dimensional information models library) which help in connectivity. LPS has an embedded library called DPALib (Data Processing Algorithm Library) which perform data processing, analysis.

III. ENABLING TECHNOLOGIES FOR IIoT

The backbone of IIoT is established by enabling a large plethora of technologies including IoT, cloud computing, big data analytics, artificial intelligence, cyber physical systems, augmented reality, virtual reality, Humane-to- Machine (H2M), and M2M communication.

3.1Internet of Things

Considering the connected factory scenario, IoT devices assist in real-time data collection and actuation. Being the primary component in IIoT, these devices track the factory assets across the globe. The whole process which is starting from raw material and ends with finish products is monitored using IoT devices in order to achieve significant reduction in labor cost and manual system management. The IoT devices in a fully connected IIoT system are deployed across all the factory facilities ranging from warehouses to production facilities and distribution centers. However, the configuration, deployment, monitoring, and maintenance of these devices is a challenging task and require highly qualified technical staff.

3.2 Blockchain Technology

The blockchain is among the most important technologies that will play a key role to bring the dream of IIoT into reality [29]. Currently, an intensive research is carried by academia and industry on blockchain technology in various fields such as finance, healthcare, supply chain, car insurance. The IoT enabled devices used in smart industry generate a huge amount of data. The data generated by these IoT devices is multipurpose, the data is analyzed and processed for performance monitoring of devices, anomaly detection, diagnosis, predictive maintenance, asset monitoring, tracking of the complete product lifecycle from raw material to finishing goods and delivery to end consumers. However, sharing this important data with all entities involved in the IIoT system in a secure manner is a very challenging task. The unique characteristics of blockchain technology like distributed nature, traceability, survivability, trust, tamper resistance, security, and inherent data provenance make it suitable for IIoT. More recently blockchain technology is utilized for IoT devices firmware updates and access control.

3.3 Cloud Computing

The massive growth of data in IIoT requires highly distributed high performance computing systems in order to manage, process, analyze, and store the data. Cloud computing technologies provide compute, network, and storage services across all the facilities in an IIoT system. All connected devices and applications are directly interfaced with backend clouds. The cloud service models are designed as private (solely owned and managed by IIoT staff), public (solely owned and managed by third-party cloud vendors), or hybrid (whereby a mix of both service models is used). Since the establishment of data centers and recruitment of technical staff require high spending therefore private cloud service models are not a viable option for newly entrants and/or small and medium level enterprises. However, large and well-established multinational enterprises prefer the deployment of private clouds in order to ensure the safety, security, and privacy and cope with industrial espionage for competitive advantage.

3.4 Big Data Analytics

The devices and systems in IIoT generate massive amount of data streams resulting the requirement of highly sophisticated high performance computing systems for big data processing and analytics. However, it is quite chal-

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lenging to specify when, how, and where to process and analyze the big data considering latency and real-timeliness in IIoT systems.

In order to fully orchestrate the big data analytics services,IIoT systems enable different tech- nologies for big data collection, storage, management, processing, analyzing, and actuation. The data collection technologies provide connectors to a large plethora of data sources including sensors, smart devices, onboard data collectors, web-enable data sources, and humane-machine movements in IIoT systems

3.5. Artificial Intelligence and Cyber Physical Systems

AI technologies ensure that IIoT system should run autonomously and intelligently to minimize the humane-interventions and improve efficiency. The AI technologies make IIoT autonomous by using complex AI technologies such as multi-agent systems and conversational AI. In addition, the intelligence is embedded at layers in IIoT systems from sensors to devices to edge servers andcloud data centers by enabling different search, optimization, and prediction algorithms. In order to minimize the human efforts and interventions, IIoT systems empower different cyber-physical systems such as manufacturing systems and industrial robots. The essence of CPS lies in onboard embedded IoT devices which enable different sensors and actuators to operate in the industrial environments. These onboard embedded IoT devices also facilitate in intelligent data processing for autonomous operations and enhance efficiency in IIoT systems. These efficiencies range from different operational efficiencies in industrial environments to system-wide efficiencies in CPS and IIoT systems.

3.6 Augmented and Virtual Reality

The Augmented Reality (AR) technologies help in aiding the industrial workers during complex operations such as assembling/de-assembling the machineries, complex industrial products, and mission critical systems. The AR technologies enable to monitor the workers and machines during operations and immediately generate alters or notifications in order to minimize the errors. The Virtual Reality (VR) technologies facilitate in visualizing the con-figurations and re-configurations of industrial functions and modules before actual implementations in IIoT systems. The use of VR enables to reduce the (re-)configuration times and cuts off the shut down time of industrial plants and machines. The VR simulations are designed by considering open standards which are designed by considering heterogeneity in CPS and IIoT.

IV. CHALLENGES

IIoT systems has brought together many technical challenges, such as interoperability, security and privacy, scalability, heterogeneity, reliability and resource management. However, there are some important challenges that are still needed to be resolved. Herein, we discuss these challenges.

4.1. Efficient Data Management Schemes

The vast adaptation of heterogeneous IIoT devices results leads to a radical increase in data volume. Sensors and actuators integrated with industrial devices generate an increased amount of sensed data streams with high velocity. The sensed data is stored on these heterogeneous IIoT devices, local gateway/edge servers and cloud servers are used for real-time and future decision making. Processing, transmission, availability, and storage of sensed data is a challenging task and require big efforts. To cup with these challenges, efficient data management models are required. These data management models should be capable of efficiently handling the huge amount of raw data generated by heterogeneous IIoT devices in an effective way. These models should also provide the data management services with high-speed data processing, reliable and secure data storage, retrieval and fast data flow.

4.2. Collaborations between Heterogeneous IIoT Systems

The suite of IIoT system is a collection of different heterogeneous and multi-vendor technologies such as industrial machine, robotics, IoT devices, sensors, actuators, gateways, edge nodes, edge/cloud data servers (data centers), different wired/ wireless communication and cellular networks (WiFi, 5G). Integration and collaboration between these heterogeneous and multi-vendor technologies based IIoT system are a challenging issue. Different factors like synchronization, resource sharing, data sharing, interoperability, and data privacy enable the integration and collaboration more challenging. More research and development efforts are still required for flexible and efficient techniques for collaboration and interoperability.

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4.3. Robust and Flexible Big Data Analytic Technologies

For achieving the vision of IIoT and getting full benefits from the high volume of data generated by IIoT devices, there is a high demand for robust and flexible big data analytics technologies. The conventional database management systems are unable to produce the desired results as these systems are unable to process and analyze the high magnitude of data efficiently. Processing the IIoT data in real time a critical task as this data is used for critical real- time industrial automation operations such as predict a malfunction, predictive maintenance, increase production, reduce down-times and anomaly detection. Thus, to meet the varying demands of IIoT applications (i.e. data rates, latency and reliability etc.) there is a need for efficient and real-time big data analytics technologies for robust and efficient processing of data generated by IIoT devices. These data analytics technologies also provide processing and visualizations of data to support the whole product life-cycle (e.g. production, testing, customer feed-backs and after sale services etc.) for getting a full insight of business.

4.4 Trust on IIoT systems

Consumer acceptance and adaptation is directly connected to the success of any technology and is highly influenced by consumer Trust on these technologies. The successful deployment of IIoT based systems by the commercial customers (e.g. owners of the particular industry) is also affected by the trust on these IIoT systems. IIoT systems are in their infancy and most of the recent research literature highlighted security and privacy as a major challenge faced by these systems. Security and privacy of technology are strongly linked with the trust of their customers, thus, weak security and privacy of IIoT systems will discourage the customers from adoptions of these IIoT systems. Therefore, for successful deployment and adaptation of IIoT systems in the industry, customer trust must be deal properly with effective customer trust models. Hence, more research in the area of customer trust models is required for the successful acceptance of IIoT systems.

V. CONCLUSION

The Industrial IoT (IIoT) system allows the industry to collect and analyze a large amount of data, that can be used, monetized and improve the overall performance of the systems for providing new types of services. In this paper, we have highlighted the latest state-of-the-art research efforts in IIoT. Particularly, three areas of research including IIoT architectures and frameworks, communication protocols and data management techniques are explored in detail. We presented various enabling technologies related to IIoT. Moreover, major open research challenges are identified for the successful deployment of IIoT.

This study concludes that the success of IIoT is hindered by a number of challenges highlighted in this study which include efficient data management schemes, collaborations between heterogeneous IIoT systems, robust and flexible big data analytic technologies, trust on IIoT systems, coexistence of wireless technologies and protocols in IIoT, enabling decentralization on the Edge, specific operating systems and public safety in IIoT. These challenges can be overcome by proposing appropriate solutions. This study can be utilized as a guideline to address some of the unresolved challenges in the field of IIoT. Our future research aims to explore the research trends in enabling personalized manufacturing in IIoT systems.

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