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Internet of Things in Industry: A Survey of Technology, Applications and Future Directions

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Abstract: Internet of Things (IoT) is a congregation of interconnected physical objects that are linked with unique identifiers and transfer data in the appropriate network without human intervention. It has the promising opportunity to develop powerful industrial applications. To understand the development in industrial IoT, this paper reviews various business values in industrial application, its architecture, related technical elements, benefits and challenges. Even though it delivers many business values, shop floor visibility, supply chain management, health, safety & environment, predictive maintenance, industrial digit thread, supply chain integration, human machine interface, quality control and big data are discussed in this paper. The major elements related to IoT like Identification, Sensing, communication methodology, computation methods and services are deliberated in this paper. Future research areas are gathered from various literatures and discussed in this paper. The key contribution of this work is to summarize the current contemporary of IoT in industries systematically.
Keywords: IIoT, IIoT architecture, IIoT technical elements

I. INTRODUCTION

Megatrends and disruptive technologies are the key concepts in shaping the future of manufacturing. In recent years, Industry 4.0 plays a vital role in enhancing the global manufacturing. Industry 4.0 is the fourth industrial revolution, it leads to digitisation in the manufacturing industries and bring the potential of IoT (Internet of things) with machine learning and big data.

As per CISCO report, the number of connected devices on earth will be more than 30 billion in the year 2020. This will generate mountains of data. This kind of information will help the organisations to understand their demand in the market and to understand the customers better. Also, it enables the manufacturers to realize the digital transformation from various perspectives: automation, efficiency, predictive maintenance, inventory optimisation, supply chain management, customer satisfaction and the benefits which are derived using data across the manufacturing value chain. Smart manufacturing marries related information, innovation techniques and human skills to realize the speedier revolution in the improvement and usage of manufacturing insights in every part of the business [3]. Basically, this will change the method of product design, manufacturing methodology, shipment and invoicing. This will improve the manufacturing environment by making zero emissions and zero incidents. There is no specific definition of smart manufacturing. NIST (National Institute of Standards and Technology) defines smart manufacturing is completely integrated, a collective manufacturing system that gives real-time information to handle the fluctuating demands and conditions in the production environment, supply chain, and customer requirement. The important characteristics of the cyber-physical system and the initiatives of Germany's Industry 4.0 and the manufacturing efforts deliberated in various countries are discussed in [4]. In [5], various literature related to the technologies identified for smart manufacturing and the future trends were reviewed. The data analytics in manufacturing are discussed in [6]. [6] Discussed the problems identified and faced with the data-driven decision making. IoT, Cloud computing, and other service-oriented solutions are discussed in [7]. The cloud manufacturing technology is outlined in this paper. [8] Discussed the smart manufacturing concept handled with IoT and wireless technologies. The behavior of smart manufacturing objects is monitored with the help of data analytics tool. In [9], short-term supply chain related scheduling discussed related to the smart factory.

In the proposed scheduling method, dynamic jobs flow and time-based decomposition was developed. The rest of this paper is organized as follows: Various IoT applications and its business value are discussed in Section 2. Sections 3 and 4 discuss the overall architecture of the IoT and its elements, respectively. Benefits and Challenges are deliberated in Section 4 and the Future research directions are discussed in Section 4. Section 5 presents the conclusion of this literature study.

II. INDUSTRIAL APPLICATIONS AND ITS BUSINESS VALUE

This section discusses about the application of the Internet of things from an industry perspective.

A. Shopfloor Visibility

Smart manufacturing offers real-time online visibility and delivers the visibility of data beyond the normal dashboard. SBEMS (Sensor based efficiency monitoring system) [10] and TBEMS (ToC based efficiency monitoring system [43] represent a real-time online shop floor monitoring system for making smart decisions. SBEMS and TBEMS brings the online visibility and efficiency of machinery and operators, machine running status, number of items produced, inventory status, rejections along with respective reasons in the cloud environment. This is achieved by installing various sensors in shop floor machines and integrated with the data acquisition in the industrial network.

B. Supply Chain Management [11]

Early prediction of failures through real-time supply chain information helps to reduce the inventory and capital investments. IoT in the supply chain helps the manufacturers to get the better understanding of this information. The visibility can be achieved by connecting plants and suppliers. This helps the suppliers to track the materials, remote monitoring of inventory status and the product movement. The delivery information can also be integrated with ERP (Enterprise Resource Planning), PLM (Product Lifecycle Management) and other systems.

C. Health, Safety And Environment [11]

Health and safety related performance indicators include illness rates, incidents, absenteeism, near-misses and property damage. In general, this kind of measurements is stored in spreadsheets and emails. The indicators do not have relational value and identification of root cause analysis becomes difficult. The industrial internet and analytics will help to identify and address this kind of health-related issues based on the data collected from various sources.

D. Predictive Maintenance [10]

Early monitoring of machines gives a high rate of ROI (Return On Investment) in different scenarios by improving the machine life, decreasing the asset downtime, increase in production and enabling the early prediction of services for the critical machines.

E. Industrial Digital Thread[12]

Service engineers often do not have right data or insights required to troubleshoot the industrial machines to perform the corrective and preventive maintenance activities. Many times, QA engineers may require right data to understand the root cause of the problem. The root cause of the problem may relate to design, manufacturing, supply chain logistics or production planning. It is very difficult to identify the problem without right data and insights. [12] discussed various types of industrial related digital application.

F. Supply Chain Integration [13]

Based on the profiles and processes, the supply chains are different in different industries. The impact of IoT in the supply chain will vary from domain to domain. For example, in the year 2018, the IDC predicted that the digital connectivity will improve 15% productivity in manufacturing supply chains.

Application of IoT provides data about product-related inventories, the location of the consignment, ambient temperature and various other parameters. By considering all these data, organizations can take immediate action to maintain the inventory level, predict the arrival time of the material and possible delays and quality related issues.

G. Human Machine Interface [14]

The collaboration between the human and the interface will not only improve the productivity in the manufacturing system, but also the safety of the operator. The human and IoT device interactions, improved with the neuroergonomics approach. Neuroergonomics is related to the human brain related to the behaviour at work and everyday activities.

H. Quality Control [16]

The sensors gather cumulative product data and data from various phases of a product cycle. This data shares the product related information like temperature, rejections, pressure, working environment and transportation-related details. The IoT device provide data about the customer specification of the product. All these inputs can further be analysed to detect and correct the quality issues.

I. Using the power of Big Data [17],[28],[29],[30],[31]

Using Big data, insights can be derived which is not possible few years before. The greatest benefits of the big data in the manufacturing industries is to detect the defect of the product well before and improve the quality of the product to meet the supplies on time. The key challenges for the industries in the smart environment are the selection of appropriate IoT architecture. The next section discusses about the related IoT architecture.

III. INDUSTRIAL IOT ARCHITECTURE

The selection of IoT Architecture is application dependent. This section describes different industrial IoT architectures implemented for different application.

The development of robotic machines, IoT principles, big data development, automation and the digital records leads to the fourth industrial revolution. The communication should bring trust between the elements of the IoT; controlling over the different parameters and finished components. [15] describes the potential ways of integrating IoT and blockchain technologies to solve the issues in the IoT connectivity. An innovative architecture has been developed by the combination of Smart-M3 and blockchain platform. Key benefit and feature of the proposed architecture is to store and retrieve the smart space elements which are required for interaction.

Industrial internet architecture framework (IIAF) is defined by using the 'ISO/IEC/IEEE 42010:2011' model used in Industrial Internet consortium[16]. The IIAF identifies methodologies, procedures, and practices for a consistent description of industrial IoT architectures. This kind of framework helps easier evaluation, procedural and effective resolution to address the concerns of the stakeholder. This architecture begins from the basic framework and requires common architecture patterns to ensure the suitability to the industrial IoT application across all industrial sectors. The general architecture framework for the real-time environment requires proper transformation and extending the abstract architecture models into detailed architecture, addressing the industrial internet application model, thereby moving to the next level of architecture and system. Through the viewpoint of this reference architecture, offers guidance to system lifecycle processes from IIoT system conception, to design and implementation. The viewpoint of this model provides a framework for the system designers to anticipate continued through common architecture related issues in IIoT system design.

[19] discussed the implementation of IIoT at various level. The smart manufacturing enterprises started the implementation of machine performance and smart enterprise control. This methodology will amalgamate the next generation of the Industrial IoT systems. In addition to this, the expanding power of embedded electronics, communication-related intelligence will move to the lower levels of the automation with the combination of sensors and actuators. Finally, the information technology (IT) and operations technology (OT) combined together and achieved the information-driven architecture. The architectures used in the past will not work in the future.

Rami 4.0 is an IoT architecture [20] contains two layers. Exchange of information across both the layers will be transparent using semantics and data recovery based on the industry standard. The first layer is the time-sensitive layer used for real-time deterministic control This is indicated as 'fog' or 'edge'.

The term time-based IP related to the technology included in this layer is equivalent to the same IIoT technology used in the enterprise cloud layer. But this communication technique is optimized for the real time. In the second layer, the devices are connected with sensors, actuators, and controllers in the cloud. The intelligence added to the devices. The second layer is the cloud enterprise layer. It includes the connectivity with various enterprise applications like ERP (Enterprise Resource Planning), SCM (Supply Chain Management), CRM (Customer relationship management) etc.

Michael Weyrich [22] discussed the Reference Architecture (IIRA) has a strong industry focus. The Internet of Things—Architecture (IoT-A) provides a detailed view of the IoT's information technology aspects. Major standardization is happening in M2M communication, employing of client, scalable, and secure communication stacks. This standardization is based on a modified Open Systems Interconnection (OSI) stack and proposes specifications for the data link, adaptation, network, and transport layers.

The IoT architecture is application specific. Understanding the various elements related to IoT will help to understand the functionality of the architecture. Next session discusses various IoT elements.

IV. IOT ELEMENTS

Understanding the basic building blocks of IoT will help to gain good knowledge and understand the functionality of the IoT. The major elements of IoT are discussed in this section.

A. Identification Methods

Identification of objects is important for the IoT. Several identification methods are available such as uCode(Ubiquitous codes) and EPC(Electronic product code). IPv6 and IPv4 are different addressing methods used for IoT objects. 6LoWPAN is the combination of IPv6 and low power wireless networks. The address helps to identify the objects uniquely. The addressing helps to identify the objects uniquely. Within the network, identification methods are used to provide clearly identify for every object.

B. IoT Sensors

A sensor[23] is a physical device provides status the physical process in a measurable way. Smart sensors are different from the usual sensors. These type of sensors are embedded in microprocessor, storage, diagnostic tool and it passes the traditional signals in the form of real digital insights. It provides time and valuable data to power analytical insights and provides a good improvement in cost, performance, and good customer experience. The speedier transformation of physical information can increase the range of opportunities for higher performance, increased capacity, maximum reliability, and innovation.

C. Communication

Connectivity technologies provide the links that make the IoT possible. Both wired networks and wireless communication play important roles. Wired fast Ethernet with IP addressing is spreading into areas such as sensor links which previously communicated via simple circuits or proprietary protocols. Mobile communications are taking over from wired networks when the speed and capacity are adequate. Local area networks based on Wi-Fi 802.11 fill in the wireless gaps between short-range communications technologies such as RFID and main Internet connections or cellular networks. When IP addresses are assigned down to the sensor level, data analysis and processing become flexible and adaptable. If more data points are needed, additional data can be obtained from the sensor by fetching the readings more frequently. Changes in the process become changes in software applications. Wired Ethernet is still the workhorse of factory automation and has the unparalleled bandwidth, speed, and reliability. Possible cable damage and broken connections are a disadvantage that designers can address the mechanical protection of wires and software checking of links by regularly calling up the IP addresses of linked devices. High immunity to interference from electrical machinery is an added benefit [26].

D. Computation Methods

The processing units represent the computational ability of the IoT. Arduino, Raspberry PI, Gadgeteer, Cubieboard, Z1WiSense and T-More are various hardware platforms used for running the IoT applications. Various softwares are available to deliver IoT functionalities. RTOS (Real time operating system) is useful for developing IoT applications in real time. TinyOS, LiteOS and Riot OS offer light weight OS developed for IoT environments. To achieve the vision of IoV (Internet of Vehicles), some automotive leaders established OAA(Open Auto Alliance) and planning to facilitate new feature to the Android platform.

Cloud computing help to transfer their data to the cloud to prepare the big data in the real time. Cloud-centric IoT presents the idea of cloud computing forming the core of IoT with users, sensor networks, middleware and private clouds completing the paradigm [33]. considering IoT from a scaled back perspective, such a representation becomes accurate. For SSGs consideration must be given to smaller infrastructure that require IoT cloud [34].

E. Services

The IoT services can be classified into Identification services, Data collection services, Collaborative aware services and Ubiquitous services. Identification services is an important service, it identifies the objects to connect to the real world. Data collection services handle the data collection and summarization of raw data which is required for further processing and reporting to the IoT application. The decision making and action is handled by the collaborative aware service. This helps to provide information anywhere, any time to anyone. Ubiquitous services will make it possible to reach the services globally. Addressing the challenges in this service is very difficult. Hence, many applications provide only the services, except ubiquitous.

V. BENEFITS IN INDUSTRIAL IOT

Following are the benefits of implementing IoT in the manufacturing production [27]

1) *Predictive Maintenance:* The usage of IoT in the manufacturing line will improve the machine uptime and minimize the failure of the machine by predicting the failures even before they occur. This will improve the productivity and revenue and decrease the production cost.
2) *Data Analytics:* Deriving insights from the factory data is possible. The unstructured data transformed into useful information and further used to derive useful smarter business decisions. Thus the capability of data analytics is ranked as an important feature for the IoT solution.
3) *Higher Customer Satisfaction:* With the implementation of IoT in industries, the SCM (supply chain management) and production will be agile. The problem related to out-of-stock will be minimized and online and real-time response to the demand is possible. This will help the customer 's request for appropriate products which will improve the customer satisfaction rate.
4) *Gaining Competitive Advantage:* The benefits stated above will impact on the organization's competitive advantage. Being an early adopter might get the industry in important position in the future.

VI. BARRIERS TO IMPLEMENTING THE INTERNET OF THINGS IN MANUFACTURING PRODUCTION

Various challenges and barriers in implementing the IoT in the manufacturing environments are discussed below

1) *ROI Estimation:* Estimation of ROI for the Internet of Things is a major barrier for potential adopters. IoT is a latest and abstract technology, the industries must invest both IoT and integration with the currently available system. Large-scale designing is required which will modify the functionality of the current system in place.
2) *Cyber Security:* Introduction of IoT system would generate huge amounts of data called as Big Data. Further, this big data can be transferred through the cloud for data analytics and the insights can be generated. Replication of the system to the whole factory with its machines can be extended with the help of wireless controllers also. The growing number of points increases the opportunity for cyber-attacks. This needs to be addressed well.
3) *Cultural Resistance:* Many industries will have the barrier to convert the mindset of the employees in the adoption of the IoT. The main reason behind this is the people are afraid that they will be substituted by intelligent systems and they will become a liability instead of a useful manpower resource. This problem can be eliminated by including the staff early in the implementation process and provide proper education and training. So that the employees can get the skills required for the latest smart manufacturing system.
4) *Structural Problems:* Sometimes the industry's existing infrastructure will become the obstacle for the IoT implementation. If the industry's internal dynamics are not adjustable and agile, this kind of new concepts will become impossible and risky. The complexity of IoT implementation depends upon the size of the manufacturing facility. The IoT transformation includes the internal dynamics, production process, and customer relationship. The complete digital connectivity will be realised to the industries which have a more agile manufacturing facility.

VII. FUTURE RESEARCH DIRECTIONS

In this section, some of the problem areas require further research are discussed below.

1) *Scalability:* The number of connected devices will become more due to the implementation of IoT. The major problems are devices naming, access authentication, maintenance, and protection. The biggest question in front of the researchers are a selection of protocols, standards, energy sources for the devices and architectural model to support the heterogeneity of things and related applications.
2) *Architecture And Dependencies:* To connect a huge number of things (objects) are connected, it requires an appropriate architecture to provide easy connectivity, proper communication technology, control and application programs. The application decides the selection of IoT architecture. In most of the cases, it is application dependent. The identification and correction of dependency problems in the architecture have large scope in the area of research.
3) *Creating Knowledge And Big Data [42],[41],[40],[39],[38],[36],[35],[37]:* The huge amount of raw data being collected require appropriate technique to convert the raw data into useful knowledge. Selective computational techniques [28], [29], [30], [31] are required to detect and remove the dirty data from the file. The huge scope is available in the improvement of computational techniques. More research possibilities are available in this area.

4) *Interoperability:* Most of the sensor related systems are closed systems. To achieve the benefit of the IoT, it requires openness in the system to provide real-time online information. A new type of unique communication interface is required to activate the efficient information across different types of systems. A new types of techniques and theory are required to achieve openness. Remote access to various industries or to a specific product is useful to the industry. It leads to the research direction of secured data transmission.
5) *Security:* The security-related issues are major in IoT because of the physical accessibility of sensors, actuators, wireless communication and openness of the systems [32]. The security-related problems lead to serious consequences, creates damage, disruption of operation or in some cases, even loss of life.
6) *Privacy:* The IoT paradigm must be able to deliver the users request for data access and unique policies to be created and evaluated in order to decide which access to be provided or denied. The data privacy should be decided based on the application.
7) *Human in the Loop:* Humans in the loop will involve humans and operate synergistically. Even though having humans in the loop have its benefits, simulating the behaviors of the human is a big challenge due to the complicated behavioral aspect of human beings especially in the industrial environment. New research is required to understand where humans can directly control the machines, taking appropriate actions, physiological parameters of the human are modeled and supervisory control.

VIII. CONCLUSION

In a complicated cyber-physical system, IoT mixes different machines equipped with sensing, identification, network and communication methodology. In general, sensors and actuators are becoming very powerful with a low cost and smaller in size. Industries are keen on setting up IoT setup for industrial applications like automated monitoring system and predictive maintenance. Due to the fast development in technology and industrial infrastructure, IoT is expected to be one of the important application in industries. Recent researches on IoT in industries are reviewed in this paper. The application in industries related to its business value is discussed first. Next, different IoT architecture in the industrial application is analysed. Afterward, the IoT elements required for the IoT implementation are discussed. Finally, the benefits, challenges and the future research direction related to IoT are discussed for the benefit of the future IoT researchers in the industrial sector.

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