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Applications of IoT in Manufacturing

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ABSTRACT

Manufacturing is essential for realizing all products and is an indispensable element of the innovation chain. Traditional manufacturing companies currently face several challenges such as rapid technological changes, inventory problems, shortened innovation, short product life cycles, volatile demand, low prices, highly customized products, and the ability to compete in the global markets. These challenges are compelling manufacturers to embrace new technologies such as the Internet of things. The Internet of things is the next big technological revolution. It is a system of smart-enabled devices, from vacuum cleaners to cars. The manufacturing industry is leading in the adoption of IoT due to the fact that IoT has several applications in manufacturing. The industrial internet of things has boosted the productivity, security, and overall efficiency of various organizations. Manufacturing is the largest IIoT market. This paper provides several applications of IoT or IIoT in manufacturing.

KEYWORD: *manufacturing, Internet of things, Industrial Internet of things, benefits, challenges, general applications, industrial applications*

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INTRODUCTION

With the globalization of the world's economy, manufacturing companies are facing keen competition in terms of product price, function, quality, cost, lead-time, etc. At the same time, they are facing a growing pressure to meet higher environmental standards and the need to customize products. These challenges push the manufacturing industry to embrace new technologies such as the Internet of things [1].

Internet of Things (IoT) is a network of connected devices like intelligent computers, devices, and objects. It may also be regarded as a worldwide network that connects devices to the Internet and to each other using wired or wireless technology. IoT is expanding rapidly and it has been estimated that 50 billion devices will be connected to the Internet by 2020. These include smart phones, tablets, desktop computers, autonomous vehicles, refrigerators, toasters, thermostats, cameras, pet monitors, alarm systems, home appliances, insulin pumps, industrial machines, intelligent wheelchairs, wireless sensors, mobile robots, etc. [2]. The growth of the Internet of things (IoT) is drastically making impact on home and industry. The IoT has amalgamated hardware and software to the Internet, thereby creating a smarter world. The application of IoT to the manufacturing industry is known as industrial Internet of things (IIoT).

Manufacturing is the largest IIoT market. It is also the largest industry from an IoT spending (software, hardware, connectivity, and services) perspective. Manufacturing is among the industrial sectors that will be directly impacted by the disruption springing from IIoT. A smart production unit may consist of a large connected industrial system of materials, parts, machines, tools, inventory, and logistics that can relay data and communicate with each other [3].

This chapter provides various application of IoT or IIoT in manufacturing. It begins by providing an overview on IoT and IIoT. It presents some general as well as specific applications of IoT in manufacturing. It highlights the benefits and challenges of applying

IoT in manufacturing. It covers the future of IoT manufacturing. The last section concludes with comments.

OVERVIEW OF INTERNET OF THINGS

The Internet of things (IoT) is a new paradigm that promises to allow a variety of things (such as cars, refrigerators, microwaves, thermostats, mobile devices, machines, animals, people, etc.) to be augmented with networking and sensing capabilities, enabling them to work together. It is a global connected network that allows devices to interact. The term, Internet of things, was first coined by Kevin Ashton, a British entrepreneur in 1999. He meant to represent the concept of computers and machines with sensors, which are connected to the Internet to report status and accept control commands [4].

IoT is a global network of interconnected devices (such as sensors, actuators, personal electronic devices, laptops, tablets, digital cameras, smart phones, alarm systems, home appliances, or industrial machines, and other smart devices) that are enabled with technology of interacting and communicating with each other. It mainly enables the interconnection of Thing to Thing (T2T), Human to Thing (H2T) and Human to Human (H2H). By collecting and combining data from various IoT devices and using big data analytics, decision-makers can take appropriate actions with important economic, social, and environmental implications.

As shown in Figure 1, the IoT can be divided into three layers [5,6]: perception (or sensing) layer, network layer, and application layer:

1. The perception layer collects from devices, RFID tags and readers, camera, GPS, sensors. In this layer, the wireless smart systems with sensors can automatically sense and exchange information among different devices and remotely control them. Anything can have sensors attached to them: people, machines, vehicles, robots, production line, etc.
2. The network layer is mainly messaging and processing information. The role of this layer is to connect all things together and allow them to share the information with each other.
3. The application layer is the Internet of things and the application systems.

Technologies associated with IoT are shown in Figure 2 [7]. These include radio frequency identification (RFID), wireless sensor networks (WSN), middleware, cloud computing, and IoT application software. These five IoT technologies are widely used for the deployment of successful IoT-based products and services. In addition to these, software defined networking (SDN) is a key enabling technology of industrial Internet of things [8].

IoT is being implemented in healthcare, wearables, smart cities, smart home, agriculture, transportation, and manufacturing industries. It has become a powerful force for manufacturing companies. Harnessing the IoT in the world of manufacturing leads to limitless possibilities. Many manufacturers use IoT is with sensors and employ IoT devices to improve efficiencies and safety. IoT technologies are designed to facilitate and optimize manufacturing processes. They are expanding from household and business use cases to industrial applications. The issue of growing competition and inexpensive connectivity have made IoT crucial and relevant in manufacturing.

INDUSTRIAL INTERNET OF THINGS

The industrial Internet of things (IIoT) is basically an application of IoT across several industries, such as manufacturing (Industry 4.0), logistics, oil and gas, transportation, energy, mining, aviation, and other industrial sectors. It can be regarded as machines, computers, and people enabling intelligent industrial operations using advanced data analytics. It is a network of systems, objects, platforms, and applications that can communicate and share intelligence. It may also be regarded as a network of intelligent devices connected to form systems that monitor, collect, exchange, and analyze data. It is the biggest and most important part of the overall IoT picture. The backbone of industrial IoT (IIoT) consists of low-powered sensors and Internet-connected devices.

IIoT is often used in the context of Industry 4.0, the industrial Internet, and related initiatives across the globe. Figure 3 shows that IIoT is the integration of Industry 4.0 and the Internet of things [9]. Industry 4.0 describes a new industrial revolution with a focus on automation, innovation, data, cyber-physical systems, processes, and people [10]. With Industry 4.0, the fourth industrial revolution is set on merging automation and information domains into the industrial Internet of things, services, and people. The communication infrastructure of Industry 4.0 allows devices to be accessible in barrier-free manner in the industrial Internet of things, without sacrificing the integrity of safety and security [11]. A typical industrial Internet of things is shown in Figure 4 [12].

The term “industrial Internet” was coined by Industrial giant GE to describe industrial transformation in the connected context of machines,

cyber-physical systems, advanced analytics, AI, people, cloud, and so on. GE and the Industrial Internet Consortium (IIC) decided that IIoT was a synonym for the industrial Internet. IIoT is poised to bring unprecedented opportunities to business and society. Organizations like IIC and IEEE are working hard to define and develop the IIoT.

IIoT can be implemented on industrial equipment, personnel, and processes, which are all interconnected. IIoT connectivity drives the convergence of operational technology (robots, conveyor belt, smart meters, generator, etc.) and information technology. Within manufacturing, intelligent sensors, distributed control, and secure software are the glue. Forward-thinking manufacturers connect their products to IIoT. They will position themselves as future leaders, while those that fail to act now risk being left behind [13]. Some innovation is necessary to improve the quality and make industrial IoT applications cost effective.

GENERAL APPLICATIONS

The industrial Internet of things, a subset of the Internet of Things, is expected to transform many industries including manufacturing. Figure 5 illustrates some of the applications of industrial Internet of things [14]. IIoT is having a profound effect on the manufacturing sector, leading to the following thirteen applications [15-17].

1. **Automation:** Every forward-thinking company strives to automate their business processes to stay ahead in the wave of ever-changing tech-innovations. The IoT or IIoT is an enabler of industrial automation. It is also proving to be a game changer for automation industry. Traditionally, plant networks are isolated from each other and from business networks. Now we can use IoT to connect everything (people, devices, equipment, etc.) within the factory and provide connectivity, communication, and information sharing. This will help manufacturers to industrial automation to create systems that are effective, affordable, and flexible to customer needs. Industrial automation companies that use IoT solutions can reap several benefits. The major benefits of using IoT in industrial automation include solving problems, enhancing operations, finding bottlenecks in the process, reducing cycle times, preventing downtime, and increasing productivity [18].
2. **Supply Chain Management:** IoT devices can track and trace the inventory system on a global scale in real-time. The IIoT-enabled systems can be configured for location tracking and remote monitoring of inventory. Manufacturers can access real-time supply chain information by using IIoT to track materials and products as they move through the supply chain. It will reduce the expenditure due to mismanagement in the organization. Smart supply chain management solutions enable manufacturers to have real-time insights into the location, status, and condition of every object and process.
3. **Inventory Management:** IoT along with RFID makes inventory management an efficient and seamless process. Each product gets an RFID tag with a unique identification number. The major role of IIoT here involves transforming the data acquired by RFID readers into useful business insights. The outputs of IoT-based inventory management can be used in different ways such as improving handling times, optimizing supply, and reducing shared costs in the value chain.
4. **Smart Automotive Manufacturing:** The smart manufacturing enterprise consists of smart machines, plants and operations all with intelligence. As the global market compels manufacturers to reconsider operations, smart manufacturing powered by IIoT-driven data analytics becomes important. The automotive industry uses IIoT devices along with industrial robots in the manufacturing process. Robots are seriously reducing downtime in automotive manufacturing. IIoT can automate many of complex process involved in manufacturing. Mobile sensors, cloud computing, and new applications are helping industrial IoT become essential to automotive manufacturing.
5. **Manufacturing Plants:** IIoT has many applications in manufacturing plants. It can facilitate the production flow in a manufacturing plant, as IoT devices automatically monitor development cycles, and manage warehouses as well as inventories. It is why investment in IoT devices has skyrocketed over the past few decades.
6. **Mining:** Today, the mining industry depends heavily on commercial systems and applications which are not interoperate. This is due to the fact that the commercial systems have their individual technology stack and data formats. This constitutes a major challenge for applying IIoT in the mining industry and slows production. Thus, the mining industry has unique challenges than other industries due to the infrastructural limitations at the mine sites, which may be underground or surface. In modern mining, there must be a real-time flow of information between enterprise level and shop floor systems. The

adoption of IIoT standards practices in the mining industry is an uphill task due to the complex nature of the mining operations. Such adoption offers safer mine site for workers, makes mining operations predictable, boosts productivity, provides interoperable environment for both traditional and modern systems/devices, reduces human intervention by automating, improves efficiency, decreases operational costs, and reduces energy usage.

7. **Pipeline Monitoring:** The oil and gas companies monitor their hardware for signs of failure as well as reduce production costs. Pipeline leaks are an important issue in the oil and gas industry. They have caused deaths, injuries, and financial loss. Any leakages in the pipeline can result in safety issues and production loss. By implementing IIoT sensors along pipelines, employees can keep a close watch on potential points of failure.

8. **Predictive Maintenance:** This will result from IoT integration. IoT facilitates predictive maintenance of your business. Many companies now use predictive maintenance. Traditionally, manufacturers use a time-based approach for the maintenance schedules of their machinery and equipment. This approach is not efficient and may prove costly. To minimize the risk of low-quality productions, manufacturers can leverage IIoT and data science for predictive maintenance. Manufacturing companies can use real-time data generated from IIoT systems to predict when an equipment will need service. IIoT takes a preventive maintenance approach to the next level by saving manufacturers a lot of money. By using sensors, cameras, and data analytics, managers can determine when a piece of machinery will fail before it actually does. They can receive signals before the machines begins to malfunction. Figure 6 illustrates predictive maintenance with IoT [19].

9. **Digital Factory:** Several processes and solutions such as manufacturing are becoming increasingly digital. A digitally connected factory will enable operation managers and factory heads to remotely manage the factory units.

10. **Digital Twin:** A digital twin is essentially a digital copy of a device or process. It refers to a digital replica of potential and actual physical assets (physical twin), processes, people, places, systems, and devices that can be used for various purposes. Technologies enabling DT include AI, IoT, 5G, virtual reality, augmented reality, wearables, and cloud computing. Manufacturing companies are highly disrupted by digital twins. Digital twins are being used to optimize the operation and maintenance of physical assets, systems, and manufacturing processes. DT has the potential to achieve smart or intelligent manufacturing. Current advancement in the Internet of things (IoT), cyber physical system (CPS), and big data continuously reshapes modern manufacturing, which requires high speed, precision and flexibility, equipment reliability, and operational safety [20].

11. **Smart Metering:** To bill a customer for utilities such as electricity, natural gas, or water, the amount the customer uses must be measured. This is usually done with a meter. In the past, the data from the meters had to be read manually by a person. IoT has been introduced utilities to the world of smart meters that can monitor the consumption of water, electric power, and other fuels. IoT sensors allow organizations to gauge the specific use of resources. Smart meters (SMs) are essentially digital meters that read remotely over a secure wireless network. Manufacturers can comprehensively analyze the results of smart meter monitoring. In spite of the many potential benefits of SMs, the deployment of SMs has created public opposition that centers on health risks and the formation of anti-smart-meter organizations [21].

12. **Smart Packaging:** IoT and packaging work together in different ways, including sensors and augmented reality/virtual reality/mixed reality options. Smart packaging provides advanced benefits of IoT for manufacturers. It enables consumers to engage with it and generate data to handle a product more effectively.

13. **Quality Control:** IoT is very useful in the areas where fast development and quality of products are the critical factors for a higher return on investment (ROI). Manufacturing happens to be one of such areas. In traditional manufacturing, a product is fabricated, the quality control unit tests it. IoT makes this process proactive with sensors collecting complete product data through different stages of a product cycle. The product is tested at each manufacturing step to check if and where the product deviates from standard specifications. The input can be analyzed to identify and correct quality issues, which can lead to significant improvement. Deviations indicate at a quality concern and measures for improvement is then taken. The IoT device can provide data about the customer sentiments on using the product. Figure 7 shows a typical system for monitoring the quality of the production process [22].

Other applications of IIoT in manufacturing include digital supply chain, retail, automotive, unmanned aerial vehicles or drones, aerospace, agriculture, data-enabled services, connected logistics, smart homes, smart grid, smart city, smart farming, smart pumping, smart packaging, asset management, energy consumption optimization, safety, predictive repairing, asset tracking, and health monitoring of workers.

INDUSTRIAL APPLICATIONS

From construction to mining, IoT offers industries new ways to improve their processes to be safer, enhance production, and increase productivity. Here, we take a comprehensive view of some companies are using industrial IoT applications and technology to drive their business forward. They are taking advantage of data explosion driven by IoT and building IoT applications [23-25].

1. **Amazon:** Reinventing Warehousing: This top online retail giant is testing the limits of automation and human-machine collaboration. The company's warehouse utilizes multitudes of Wi-Fi-associated Kiva robots. The company is an advanced innovator with regards to warehousing and logistics. The company's use of drones for delivery has won limelight from media. Their robots help the company cut its operating costs by 20%.
2. **ABB:** Smart Robotics: ABB is a Swiss-Swedish multinational corporation. The company is basically into the production of robots. The robotics and power company uses connected sensors to monitor its robots' predictive maintenance. Also related to IoT is the company's collaborative robots, designed to collaborate alongside humans. One can use ABB smart robots in the smart manufacturing process.
3. **Airbus:** Factory of the Future: This is a European multinational aerospace corporation. To tackle the complex and enormous task of assembling millions of components to make commercial jetliner, Airbus has launched a digital manufacturing process known as Factory of the Future to streamline operations and bolster production capacity. The company has been able to reduce errors, minimize the number of steps, and improve productivity by 500%.
4. **Boeing:** Using IoT to Drive Manufacturing Efficiency: The multinational company is the pioneer of aviation. The company has already made significant strides in transforming its business. The company is also using IoT in supply chain management for collecting information using the sensor. The combination of the blockchain technology and IoT into an IoT-driven blockchain is being recognized as a winning adoption by the aviation industry.
5. **Caterpillar:** An IIoT Pioneer: This is an American heavy-equipment maker. It has invested heavily in IoT technology. It is using IoT and augmented reality (AR) to give machine operators a view of everything. Caterpillar has brought about 45% efficiency into its production by using IoT.
6. **Hitachi:** An Integrated IIoT Approach: This Japanese company distinguishes itself in terms of its integration and experience across operational and information technology. Hitachi is independent in that it does not leverage partnerships to fill in the gaps in their IoT knowledge. Hitachi has built an IoT-upgraded production model that has cut creation lead times significantly.
7. **John Deere:** Self-driving Tractors and More: This is an American corporation that manufactures agricultural, forestry, and construction machinery. This company is responding to agriculture by deploying IoT technology, most notably with self-driving tractors. The company also happens to be the first company that bought the concept of GPS in tractors. It bought the self-driving vehicle revolution. It has also deployed telematics technology for predictive maintenance.
8. **Tesla:** This American automotive and energy company specializes in the manufacturing of electric vehicles. The company is leverages IT-driven data to move their business forward. They improve the functionality of the products via software updates. Tesla has changed the way the batteries were consumed. These batteries were chargeable on their own without any interruption.
9. **ADLINK Technology:** This company offers Industrial Internet of Things (IoT) platforms to serve the automation, medical, transportation, and government/defense verticals. Their products include motherboards, blades, chassis, modules, gateways, systems, and end-to-end solutions based on industry standard form factors.
10. **Shell:** The Smart Oilfield Innovator: Shell is the smartest oilfield innovator in the world. This company also uses IIoT in manufacturing. The oil company has saved tremendously by using IoT devices to monitor oil fields. For example, Shell deployed sensors to provide pipeline surveillance

and wellhead monitoring capabilities to remote infrastructure in the Nigeria.

BENEFITS

Industrial IoT will have huge impact in manufacturing. It can enhance productivity, boost operational performance, increase efficiency, increase throughput, assist asset monitoring, minimize financial risk, reduce production downtime or boost the production speed, improve product quality, reduce overhead, conserve resources, increase profits, eliminate waste, support better customer experience, and improve employee health and safety. Other benefits include [26,27]:

- **Enhancing Productivity:** All the investment on building connectivity may seem futile if one cannot make sense of the data collected. Monitoring the whole manufacturing process digitally and economically helps in boosting the productivity of the manufacturing industry.
- **Workplace Safety:** This is a top concern in the manufacturing industry. An advantage of IIoT is its ability to increase safety in manufacturing. A workers' safety in the manufacturing environment can improve by IoT combined with big data analysis. IIoT system can help assure employees' safety by monitoring equipment for potentially dangerous failures.
- **Wellbeing of Workers:** Proactive manufacturers see the pandemic related investments as a great platform to offer safety of co-workers by tracking their location. Wearable ear devices that can allow workers to set their own soundtrack.
- **Customer Satisfaction:** The issue of the customer value always comes before selecting technical solution. IIoT technology is having a great impact on customer experience by enhancing customer satisfaction. It is ushering in a new age of opportunity, enabling businesses to drive customer relationships that are closer and more profitable than ever before.
- **Asset Management:** IIoT solves some of the challenges facing asset-intensive companies. An automotive manufacturer can take advantage of IIoT to track its assets, including tools and vehicle parts. IIoT can also track asset locations with smart sensors, monitor demand-supply requirements, and manage the production accordingly. IIoT is applied in manufacturing to ensure proper asset usage and provide the best return on assets.

Other benefits include cost reduction**,** shorter time-to-market, energy management, and mass customization. Manufacturing organizations that intent to modernize cannot ignore these benefits.

CHALLENGES

The industrial Internet of things is still in its early age. Although it offers several benefits for manufacturing and is poised to grow significantly, there are challenges which can hinder future growth. Some of the challenges facing the adoption of IoT or IIoT in manufacturing include [28]:

- **Security:** A major challenge for executives is cybersecurity and data security, which is rising in importance due to increased vulnerability to attacks and data breaches. Connecting industrial machines to an interconnected system is risky. A secure environment is necessary to protect machines and employees from cyber threats. In the IIoT context, data is considered sensitive because data will encapsulate various aspects of industrial operation, including highly sensitive information about products, business strategies, and companies. The transition to more open network architectures and data sharing of IoT poses challenges in industrial markets. The loss of sensitive information can lead to significant business loss and cause reputational damage [29].
- **Interoperability:** The manufacturing processes involved in different industries vary. Interoperability between sensors, edge devices, and the cloud has always been an important challenge. Standards are not in place to ensure the transferring data between machines from different vendors.
- **Integration:** Data integration is a major challenge because it is not easy to move from data to business value. The integration of IIoT solutions into existing business processes and industrial environment brings new challenges. It is only when the data from IoT solutions is fully integrated with data from enterprise systems that the most benefits can be achieved. Integrating information technology (IT) and operational technology (OT) is another critical challenge faced by the companies during IIoT implementation.
- **Lack of Standards:** Standards are needed to enable smart connected machines, products, and assets to interact in a transparent manner. They are vital to ensure that any new device added to the infrastructure can interact with existing equipment. The question of standardization is currently being addressed by the Industry 4.0 and the Industrial Internet Consortium [30].

- **Lack of Skills:** A major challenge making companies not to be ready for the industrial Internet of things is a lack of skilled workers. As IIoT is a new area, new industry skills are required.

FUTURE OF MANUFACTURING WITH IoT

The future of manufacturing is essentially in everybody's interest. It will determine our jobs, our consumption patterns, the quality of life for this and future generations. Manufacturers must keep eye on the following disruptive technologies, which will slowly make their way into more and more facilities and collectively determine the future of manufacturing [31]:

- Robotic Automation
- Industry 4.0
- Internet of Things (IoT)
- Additive Manufacturing or 3D Printing
- Artificial Intelligence

These emerging technologies are quickly becoming the future of manufacturing. The convergence of these is incredibly important to the future of manufacturing. Other important technologies such as nanotechnology, cloud computing, business intelligence, and virtual/augmented reality are all improving manufacturing. They are pushing manufacturers to explore radically new ways of creating and capturing value. For both incumbents and new entrants, these technologies will serve as tools to successfully navigate the new landscape of manufacturing. Nations that are currently investing in these technologies are the ones that will dominate global manufacturing in the future. Although manufacturing will be dominated by new technologies, the changes will be led by humans.

The growing adoption of IoT in manufacturing is expected to boost market for networking technologies, particularly for wireless networks. The Internet of things is the answer for manufacturers looking for solutions to complete maintenance proactively. IoT refers to the connectivity between devices which are able to communicate and exchange data with one another. IoT is revolutionizing manufacturing. It may be regarded as the nerve system of a manufacturing plant. It is helping manufacturers connect and monitor the various components of their operations, gaining insight never before possible. The IoT market is growing steadily and is likely to continue to do so in the foreseeable future. The industrial Internet of things is the future of manufacturing. It refers to the use of a system of interconnected computing devices that can transfer data over a network without any human involvement.

CONCLUSION

The Internet of things (IoT) and the industrial Internet of things (IIoT) are transforming modern manufacturing. Applications of IoT have benefited in increasing the production and fulfilling the customer demand through product customization. IIoT also enables the real-time supervision [32]. The Industrial Internet of things refers to a vast number of interconnected industrial systems that are communicating, sharing data, and improving industrial performance to benefit the society. Recently, IIoT has emerged as a subparadigm which focuses more in safety-critical applications in industries like aerospace, energy, and healthcare. It may be regarded as a revolution that is changing the face of industry in a profound manner. In manufacturing, IIOT improves productivity, enhances efficiency, and drives competitive advantage. As manufacturers continue to invest and incorporate IoT into their businesses, they are accelerating the era of smart manufacturing.

Companies that want to stay competitive should embrace the IIoT as soon as possible. In virtually every industry, areas can be indentified to get started where implementation costs are low. More information about IIoT can be found in the books in [33-40] and in the following related journals: *IoT,* and *IEEE Internet of Things Journal*,

REFERENCES

[1] C. Yang, W. Shen, and X. Wang, "Applications of Internet of Things in manufacturing," *Proceedings of 2016 IEEE 20th International Conference on Computer Supported Cooperative Work in Design,* May 2016.

[2] M. N. O. Sadiku, *Emerging Internet-Based Technologies.* Boca Raton, FL: CRC Press, 2019.

[3] M. N. O. Sadiku, Y. Wang, S. Cui, and S. M. Musa, "Industrial Internet of things," *International Journal of Advances in Scientific Research and Engineering,* vol. 3, no. 11, Dec. 2017, pp. 1-4.

[4] M. N. O. Sadiku, and S. M. Musa and S. R. Nelatury, "Internet of things: An introduction," *International Journal of Engineering Research and Advanced Technology*, vol. 2, no.3, March 2016, pp. 39-43.

[5] P. Sethi and S. R. Sarangi, "Internet of things: Architectures, protocols, and applications," *Journal of Electrical and Computer Engineering,* 2017.

[6] G. Wiggins, "Chemistry on the Internet: The library on your computer," *Journal of Chemical Information and Computer Sciences*, vol. 38, October 1998, pp. 956-965.

[7] L. D. Xu, W. He, and S. Li, "Internet of things in industries: A survey," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, November 2014, pp. 2233-2243.

[8] S. Al-Rubaye et al., "Industrial Internet of thing driven by SDN platform for smart grid resiliency," *IEEE Internet of Things Journal*, August 2017.

[9] "7 Uses, applications & benefits of industrial IoT in manufacturing," https://infinite-uptime.com/blog/industrial-iot-in-manufacturing/

[10] "Predictive maintenance with IoT: The road to real returns," https://www.avnet.com/wps/portal/abacus/solutions/markets/industrial/predictive-maintenance-iot/

[11] "The industrial Internet of things (IIoT): the business guide to Industrial IoT," https://www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/

[12] D. Schulz, "FDI and the industrial Internet of things," *Proceedings of IEEE 20th Conference on Emerging Technologies & Factory Automation*, 2015, pp. 1-8.

[13] A. R. Sadeghi, C. Wachsmann, and M. Waidner, "Security and privacy challenges in industrial Internet of things," *Proceedings of the 52nd Annual Design Automation Conference*, June 2015.

[14] "The industrial Internet of things: Why it demands not only new technology – but also a new operational blueprint for your business," https://www.pwchk.com/en/migration/pdf/tmt-industrial-internet-may2016.pdf

[15] "Industrial Internet of things (IIoT)," https://internetofthingsagenda.techtarget.com/definition/Industrial-Internet-of-Things-IIoT

[16] S. Morgan, "Top 3 Applications of industrial IoT in manufacturing," https://stumpblog.com/top-3-applications-of-industrial-iot-in-manufacturing/

[17] "The six applications and benefits of IoT in manufacturing," https://www.tatatelebusiness.com/articles/the-six-applications-and-benefits-of-iot-in-manufacturing

[18] "7 Practical applications of IIoT in industrial automation," https://www.ixon.cloud/knowledge-hub/7-practical-applications-of-iiot-in-industrial-automation

[19] J. Wang et al., "Digital twin for rotating machinery fault diagnosis in smart manufacturing," *International Journal of Production Research,* vol. 57, no. 12, 2019, pp. 3920-3934.

[20] "How industrial IoT (IIoT) is revolutionizing manufacturing industry," https://iot.do/how-industrial-iot-iiot-is-revolutionizing-manufacturing-industry-2021-01

[21] M. N. O. Sadiku, S.M. Musa, A. Omotoso, and A.E. Shadare, "A primer on smart meters," *International Journal of Trend in Research and Development,* vol. 5, no. 4, 2018, pp. 65-67.

[22] B. Shiklo, "IoT in manufacturing: The ultimate guide," https://www.scnsoft.com/blog/iot-in-manufacturing

[23] "The top 20 industrial IoT applications," https://www.iotworldtoday.com/2017/09/20/top-20-industrial-iot-applications/

[24] "Reasons why people like 10 industrial IoT applications in practice from top companies?" May 2020, https://dxminds.com/why-people-like-10-industrial-iot-applications-in-practice-from-top-companies/

[25] "Learn IIoT: IoT in manufacturing for industrial automation," https://www.fossguru.com/learn-iiot-iot-in-manufacturing-for-industrial-automation/

[26] A. Aziz, O. Schelén, and U. Bodin, "A study on industrial IoT for the mining industry: Synthesized architecture and open research directions," IoT, vol. 1, 2020, pp. 529–550.

[27] K. S. Wong and M. H. Kim, "Privacy protection for data-driven smart manufacturing systems," *International Journal of Web Services Research*, vol. 14, no. 3, July 2017, pp. 17-32.

[28] J. Conway, "The industrial Internet of things: an evolution to a smart maufacutirng enterprise,"http://www.mcrockcapital.com/uploads/1/0/9/6/10961847/schneider-an_evolution_to_a_smart_manufacturing_enterprise.pdf

[29] "How to succeed with industrial IoT in manufacturing," https://business-reporter.co.uk/2019/07/15/how-to-succeed-with-industrial-iot-in-manufacturing/

[30] "What is Industrial IoT or IIoT?" Unknown Source.

[31] M. N. O. Sadiku, O. D. Olaleye, A. Ajayi-Majebi, and S. M. Musa, "Future of manufacturing," *International Journal of Trend in Research and Development,* vol. 8, no. 1, Jan.-Feb. 2021, pp. 194-197.

[32] M. H. F. Fauadi et al., "Recent applications of Internet of things (IoT) in manufacturing sector–A review," *International Journal of Scientific & Technology Research*, vol. 9, no. 9, September 2020, pp. 334-339.

[33] G. Veneri and A. Capasso, *Hands-On Industrial Internet of Things: Create a Powerful Industrial IoT Infrastructure Using Industry 4.0.* Packt Publishing, 2018.

[34] S. Bhattacharjee, *Practical Industrial Internet of Things Security: A Practitioner's Guide To Securing Connected Industries.* Packt Publishing, 2018.

[35] S. Misra, *Introduction to Industrial Internet of Things and Industry 4.0.* Boca Raton, FL: CRC Press, 2020.

[36] S. Jeschke et al., *Industrial Internet of Things: Cybermanufacturing Systems.* Springer, 2016.

[37] A. Gilchrist, *Industry 4.0: The Industrial Internet of Things*. Apress, 2016.

[38] S. Goundar et al., *Innovations in the Industrial Internet of Things (IIoT) and Smart Factory.* IGI Global, 2021.

[39] J. Y. Khan and M. R. Yuce (eds.), *Internet of Things (IoT): Systems and Applications*. Jenny Stanford Publishing, 2019.

[40] D. Gupta et al. (eds.), *Smart Sensors for Industrial Internet of Things: Challenges, Solutions and Applications.* Springer, 2021.

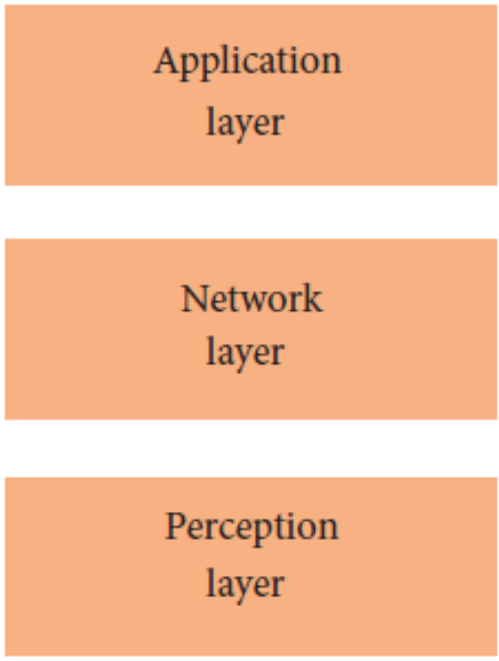

Figure 1 The architecture of IoT [5].

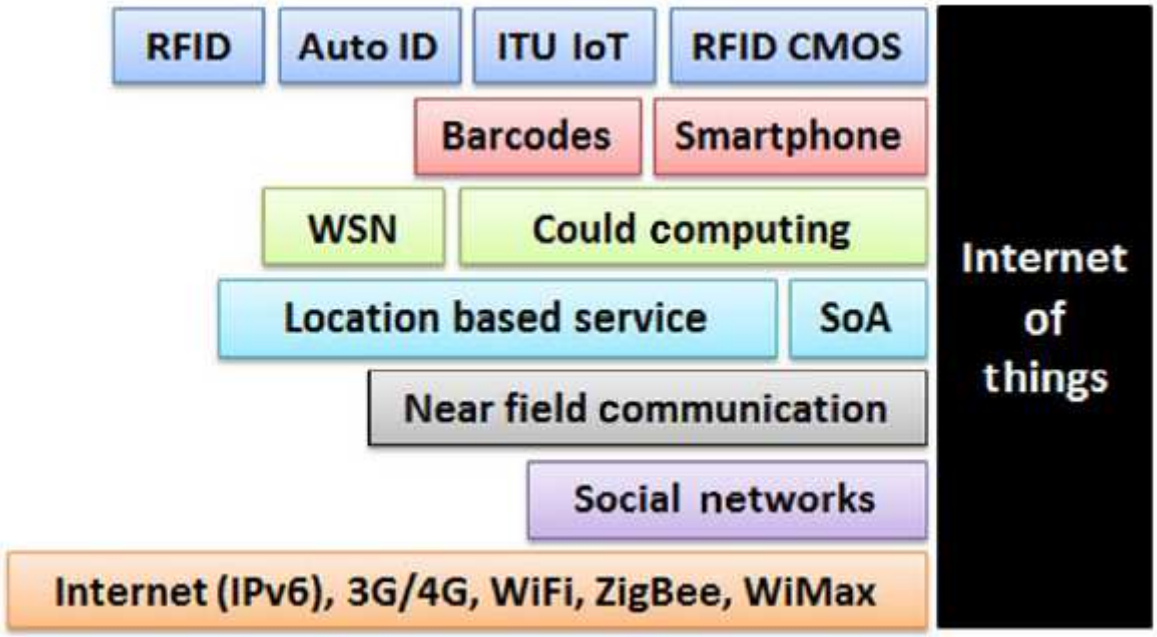

Figure 2 Technologies associated with IoT [7].

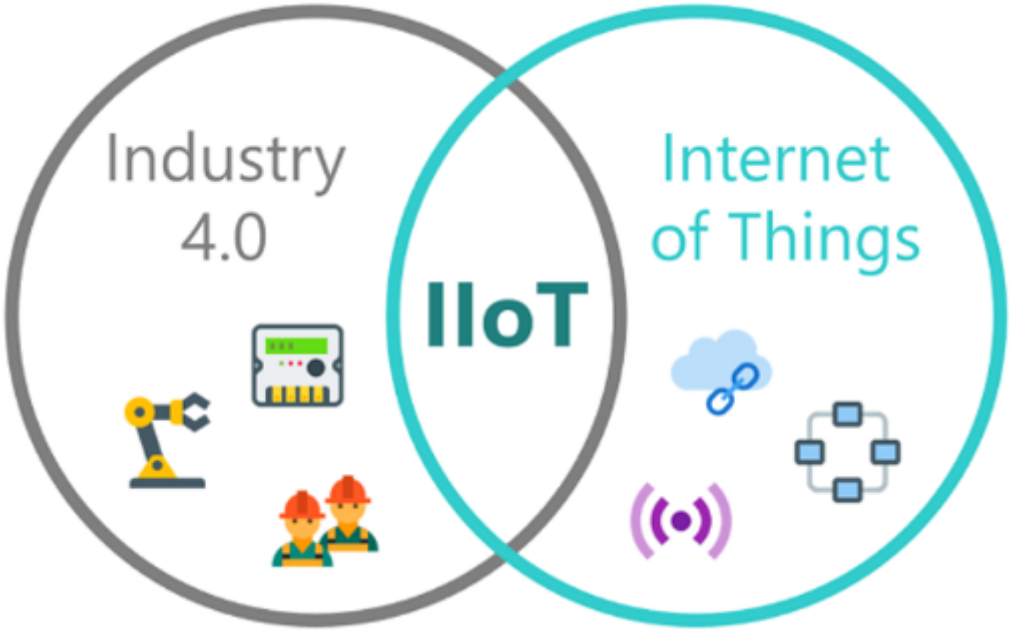

Figure 3 IIoT is the integration of Industry 4.0 and the Internet of things [9].

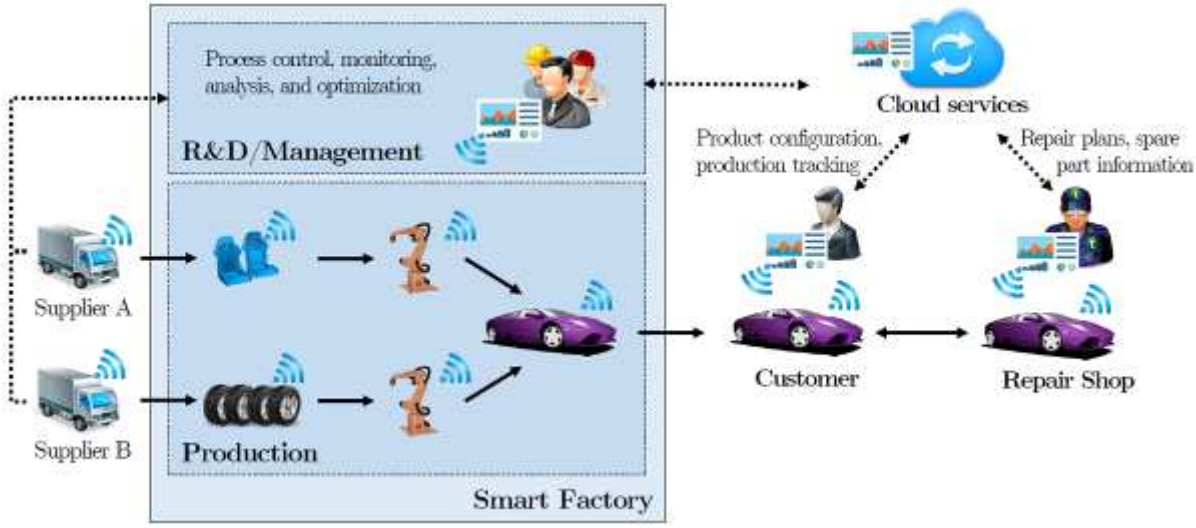

Figure 4 A typical industrial Internet of things [12].

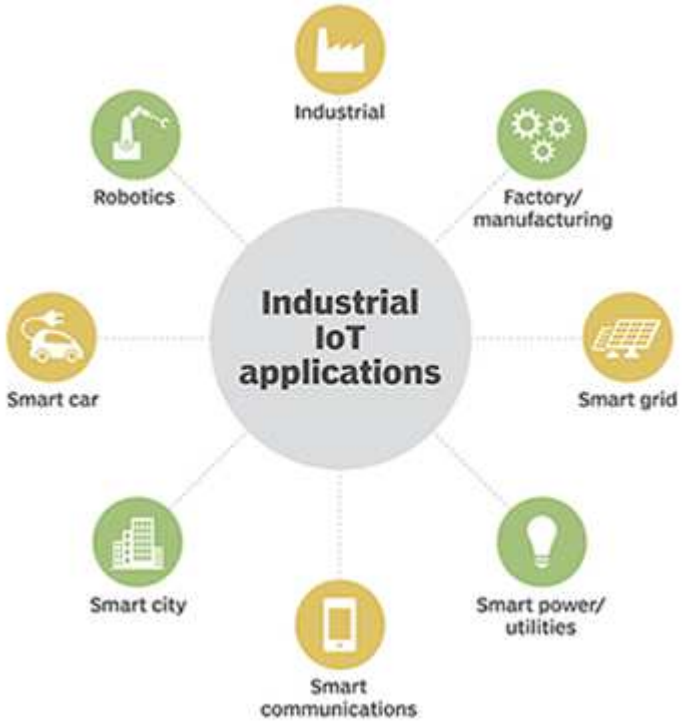

Figure 5 Applications of industrial Internet of things [14].

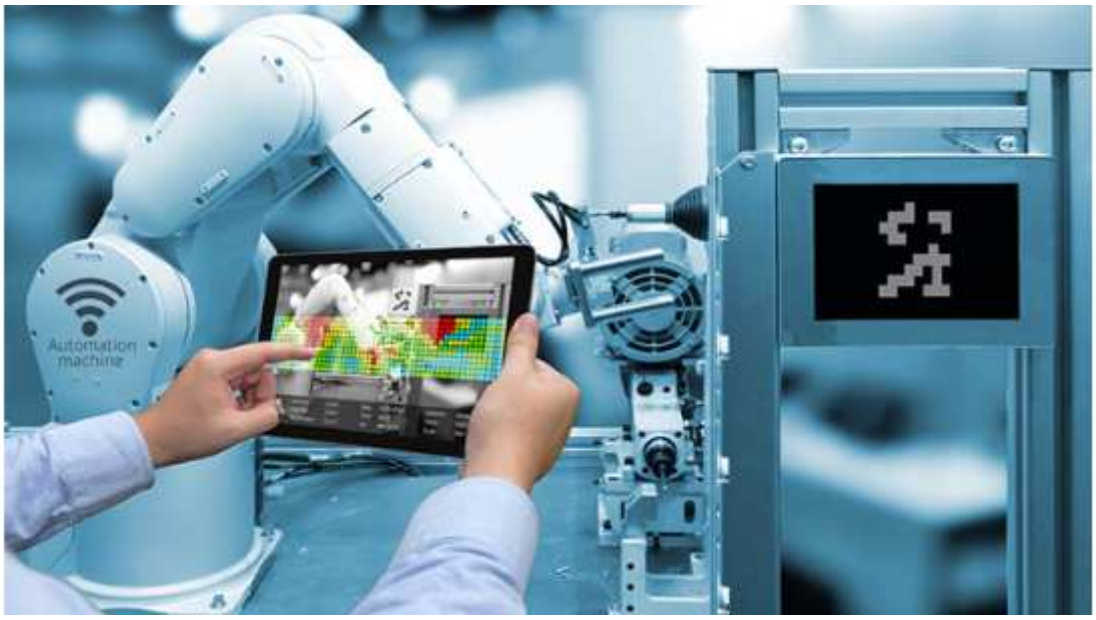

Figure 6 Predictive maintenance with IoT [19]

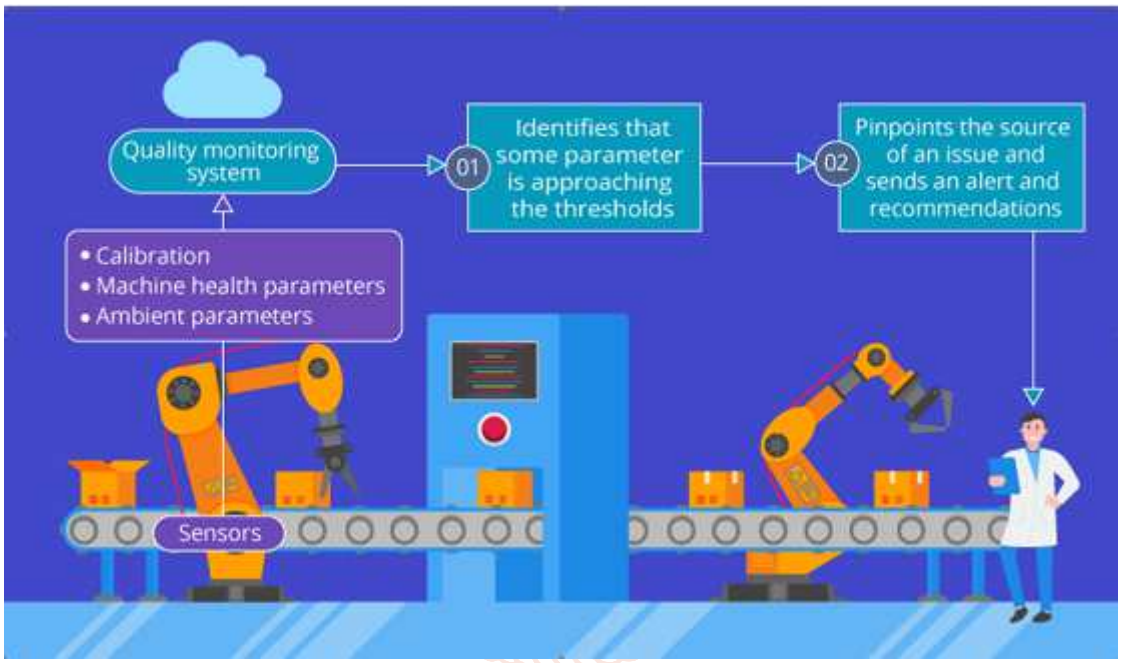

Figure 7 A typical systems for monitoring the quality of the production process [22]