Internet of Things (IoT) in smart manufacturing

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Abstract: Rapid growth in the manufacturing sector has triggered to explore the potentials of Wireless Sensor Networks (WSN) and Internet of Things (IoT) which paves the way to escalate the efficacy of manufacturing. Industries implemented IoT in various domains starting from purchase of raw materials till customer service and support. IoT is considered as a key technology of the industrial revolution 4.0 and this provides a promising prospect to build influential services and applications for manufacturing. Further, it also provides an interactive relation between smart machines to share the data and information, which is essential for the complex systems to take a decision on the real-time working environment. In this paper, we reviewed the impact of IoT for a sustainable development, especially with regard to the manufacturing dimensions. This will further put forth the current scenario of IoT in manufacturing and this leads the researchers for pioneering their research towards the cyber integrated manufacturing.

1. Introduction
From the time of the Industrial Revolution, the manufacturing sector has played a dominant role in the economy of the countries and companies. We are in the new era of modern industrial revolution 4.0 where, the cyber integrated manufacturing is a pressing matter. An IoT enabled smart manufacturing provides an interactive relation between smart machines to share the data and information, which is essential for the complex systems to take a decision on the real-time working environment [1-8]. In the day to day point of view, attaining the growth in the resources and energy efficiency is the key strategy to reach the sustainability in manufacturing [9]. Business organizations face many challenges in the recent days due to technological advancement and extreme global competition. In order to overcome these issues, innovation in their product and processes is necessary for entering into the sustainable development in their future. IoT is the technology through which the companies are focusing to enhance their product and process development. Even though there is a tremendous growth of IoT in various sectors such as health care, energy managing, smart retail, agriculture, etc., the implementation of IoT in the manufacturing sector is in infancy. The majority of the manufacturing process still depends upon the third industrial revolution
which is called the digital revolution where there is an emergence of electronics such as transistor, microprocessor, telecommunication and computers.

This revolution led to the development of automation in the production such as programmable logic controllers (PLCs) and robots. These provisions paved the way for more production in industries with less time and economy. But due to high competition and globalization, the industries are looking for the next level of technological advancement. New business models incorporated with IoT enable the organizations to develop innovative products with high productivity. The manufacturing industries are enforced to produce more products by using less raw materials and less energy. The aforesaid survey estimated that smart production line and industries would result in an annual efficiency surge of 3.3 over the next few years resulting in 2.6% annual cost savings. This puts forth the companies to invest in IoT and a recent survey estimated that about 140 billion euro will be endowed by the European companies in renovating the ways they manufacture the products [10]. The well sophisticated IoT network leads to the informed manufacturing in an organization which connects the four basic elements such as products, people, processes and infrastructure [11]. This enhances the entire process of an organization from the supply of raw materials to the customer service. The IoT has many more advantages in the manufacturing sector, such as the empowered connection between manufacturers and machines, smarter business decisions, improved management of the global supply chain [12].

2. Challenges for Smart Manufacturing

IoT leads to the enhancement of the product quality and manufacturing process efficiency, but still there are huge uncertainty issues which the industries face during the implementation [13]. There are three big challenges identified [14], one is general hesitancy of machine builders and end users to actually contrivance this technology. The second one is the security issues, where the collected information about the industry has to be made as big data and to be shared with the co-partners for making it really a IoT cultured organization. Finally, partnering the other industries, where only a few industries make it possible to bring all the supporting firms into one coherent package [15]. System integration is the biggest challenge to implement IoT and development of a connected manufacturing strategy. Various practical challenges [16] in implementing IoT is listed below

2.1 Vertical sector specific needs

Each vertical sector in manufacturing has different process and need of diverse gateways and platforms to collect the data from various sensors of different sensitivity levels. Connecting all the devices is the major challenge encountered in IoT and this will vary the entire communication protocol and the underlying technologies. Presently the centralized paradigm is used to collect the data from different nodes in the network [17]. But it will be complex to maintain the same strategy in the future, if the devices which are to be connected are in the billions. Also, the maintenance cost of cloud computing will be very high to maintain this vast data. In future a decentralized network will be required to connect the different nodes in the network. Each node will communicate with other node with a unique authentication directly without a broker in-between. This communication technique also has a disadvantage of security issues which can be overcome by the recent technologies such as blockchain [18].
2.2 Security
Data retrieved from smart manufacturing should be stored in the cloud which can be utilized by the stakeholders to observe the enactment of every process in manufacturing and ensure a robust control and adapt industrious measures using real-time information. Security plays a vital concern when developing the smart factories. Different frameworks are analyzed by the researchers to ensure the security and privacy in the network [19-20]. Today the vast information available on the internet has facilitated hackers to identify the weak spots and liabilities of “Smart Businesses”. The data transfer from industrial unit to the cloud server should be fully secured. The list of security issues and its precautions are given in the table 1[21].

| Security issues               | Description                                                                 | Precautions                                                                                           |
|------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Secure constrained devices   | Less capability devices (memory, storage, processing capability) are not suitable for carrying out complex encryption and decryption quickly which is very essential for security approaches | Multiple defensive layer should be implemented to separate devices into separate networks and using firewalls, to compensate for these device limitations |
| Device authentication        | Unique identification should be provided to the devices before they can access platforms and upstream services and apps | Two factor authentication (2FA) and imposing the usage of robust passwords or certificates is recommended |
| Managing device updates      | Devices might be temporarily towed from production for updation and also updation will be not available for older devices where these are no more supported by the manufacturer | The device administrator should automatically update the devices and to keep a track on the current level of updating required for devices and also on the retirement of devices |
| Safe communications          | Soon after the device is secured the next is to safeguard their communication | Sending the encrypted communication between the devices. A separate network is to be used to isolated the devices such that the communication will be confidential |
Data privacy and integrity
After the data communication, it has to be stored securely and the unwanted communication should be eliminated

Employ the digital signature to confirm that the data is not altered and using the safety technique such as blockchain to preserve the data from hackers

Secure cloud applications
Cloud apps are used to control and process IoT devices and these are also to be protected as a multi-layer slant to IoT security

Apps should be provided with protected authentication, for both the apps and the users, by providing options such as 2FA and secure password recovery options

Availability
Unavailability of IoT data and app leads to the revenue loss, destruction to the tools and life threatening issues

Ensure availability by including redundancy to avoid one point failure and should be resilient and fault tolerant

Predict and Manage vulnerabilities
Precautions must be implemented to identify the area of fault occurrence and security measures should be applied for both real time issues and future

Use predictive techniques and Artificial Intelligence to predict the future issues from the past performance

2.3 Standards
Connectivity and utility standards are very big challenges to implement the IoT. There are many different proprietary methods and custom integration solutions followed by the manufacturers. Standardization leads to the interaction of machines and assets in a translucent fashion. Standardization involves the creation of standard mechanisms that will allow the devices to interoperate. The mostly used standard in IoT is IEEE 802.15.4 which includes the communication technology such as ZigBee [22]. Continuous research is in progress to develop the sustainable standard for IoT.

2.4 Human Machines Interfaces
Human Machine Interface (HMI) facilitates an interaction between the human operator and machine with a mode of remote control in industries [23]. Mobile applications have a vital role in managing Industrial Control Systems (ICSs) but it is not suited for the task of learning, allocating, and building HMIs. Hence speciality framework such as No Effort Rapid Development (NERD) is developed to achieve a high level HMI [24]. IoT favors the communication between human and machine by providing the real time
information about the process. ‘Informed people’ leads to smart design, intelligent operations, maintenance, quality service and safety.

Table 2. IoT in sustainable manufacturing [25]

| Sustainability issues                  | Description                                                                                                                                 |
|----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Reducing product miles                 | Using IoT enabled smart product tracking, detect the optimal route for the products to reach the destination from the starting point and thus making the distribution much more proficient so that customers get the goods at the right time |
| Lengthening the life of machinery and tools | The life time of the product can be significantly increased by tracking and constantly monitoring the performance. The maintenance requirement of the product is easily determined and further this can enhance the efficiency of the product |
| Preserving energy and water            | IoT enabled manufacturing unit can facilitate the managers about the usage of energy in various units such as heating and cooling systems. This paves the way for making the effective utilization of energy. Also waste management can be effectively tackled by IoT enabled systems |
| Make supply chains smarter             | IoT technology enable to provide remotely monitor and automation of the gadgets which is located in multiple locations including the supplier and customer locations and retrieving the data back to the central database for future purpose. |

3. An IoT enabled Smart Manufacturing
To enable an IoT integrated smart manufacturing three major building blocks are required as shown in Figure 1 [26], the first one is the sensing nodes. The sensing devices which are used in IoT environment may vary widely depending upon the application. It may be a camera for image monitoring, Radio Frequency Identification (RFID) reader to sense the existence of an object/person or a simple thermocouple measuring temperature. The second building block is the embedded processing nodes, which may be a hybrid microcontroller or microprocessor which the embedded processing takes place in real time mode. The third one is the wired or wireless communication nodes, which transfer the communication between the two former building blocks to execute a task. It is generally a two way communication node.
Figure 1. Building blocks of an IoT enabled smart manufacturing

The pervasiveness of IoT enabled manufacturing not only confined to a particular localized industry segment or value chain process, rather it is applicable for multiple segments of manufacturing and logistics as shown in Figure 2. The potential of IoT in various segments is given as follows

3.1 Transportation and logistics
In IoT enabled transportation and logistics, the products are incorporated with sensors along embedded tags [27]. When the product moves, the flow can be traced by various participants in the supply chain. Further, the product becomes totally autonomous and various decisions can be taken by the readers from the obtained information. This leads to the end to end visibility in the supply chain and warehouse management, ensuring that the product is in the right place at the right time. Optimal fleet management is also possible where the fleet downtime is considerably reduced.
3.2 Factory visibility
When the factory is equipped with IoT, then it paves the way to access the real time information and efficient collaboration [28]. A plant manager can be informed the status of machines and production from any locations and this can considerably reduce the downtime for decision and action. The quality control can be effectively achieved by shutting down the production process when the problem is known in advance and the product wastage is totally eliminated. The benefit of factory visibility extends to the suppliers and third party participants.

3.3 Automation
The IoT and Internet Protocol (IP) network is used to connect the entire network and provide connectivity and information sharing across multiple business networks. Flexible and compliant automation needs a complete industrial IoT elucidation that addresses business, technologies, and facility aspects in order to (i) deliver real-time control for optimization and enhanced uptime; (ii) empower the horizontal association between devices; and (iii) offer protected and expected inclusion of service features [29].

3.4 Energy management
Energy plays a vital role in manufacturing and is often the second major operating cost. But many industries are lagging in modeling tools or management tools to optimize energy usage in industrial operations. Certain IoT enabled plants offers integrated energy data and prediction analysis. Hyunjeong Lee et. al. 2016 [30] proposed an energy management framework for smart factory where the smart factory consist of three layers. The first layer is the sensor layer which collects the data and send to the second layer where it analyses the data and infers the context and finally to the third layer where the energy management is achieved through monitoring and controlling the status of energy consumption.

4. Benefits of IoT in Smart Manufacturing

4.1 Greater Energy Efficiency
Energy plays a significant role in the expenses for manufacturing industries. Industries measure their expenses for energy conception from the bill that is generated. It is very complex or not possible to detect the inefficient power conception from the available data. Nearly 77 % percent of industries retrieve their energy consumption data from their monthly utility bills or energy utilization monitoring facility, where the data available is limited [31]. Implementing IoT can access the data from the device level and it is possible to pinpoint the devices which are under performing. By tracking the power conception of each device separately, managers acquire visibility to benchmark the under performing devices with the best performing devices. Energy utilization is optimized and much of the

4.2 Predictive Maintenance
IoT completely eliminates the conventional method of maintenance by mere guessing from the historical data, but instead realizing the maintenance requirement for the device at the exact moment by obtaining the real data. The sensor gives the condition of each component and if it doesn’t need maintenance the replacement is totally eliminated and money and time are saved. These circumstantial perceptions keep the equipment at good running condition and minimize the risk of costly downtime. Recent analysis shows that
the market for predictive maintenance applications is poised to grow from $2.2B in 2017 to $10.9B by 2022, at an 39% annual growth rate. According to recent research IoT and advances in analytics leads to an efficiency gain of 25% - 30% in industries implementing the IoT enabled predictive maintenance. Few of the top listed companies in the world, providing IoT solutions in the predictive maintenance [32] is shown in the table 3.

4.3 Higher Product Quality
IoT can help in quality improvement of product which leads to achieve waste reduction, lowering the costs, increased customer satisfaction and higher sales. One of the major causes for quality is fault equipment.
These kind of problems can be overcome by the IoT technology. The various quality improvement enabled by the IoT is given in the table 4 [33].

**Table 4. Quality improvement enabled by the IoT**

| Quality Improvements                              | Description                                                                                                                                 |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Avoiding performance degradation                  | An integrated sensor with a remote software to avoid fault in the system and send an instruction note to the customer to handle the particular problem |
| Refining warranty costs and service contract profitability | Connected device permit the identification of issues in the system and this leads to early detection and prevention of faults. This gains the satisfaction of the customer |
| Termination of scrap and rework                   | In a networked manufacturing process, the machines can communicate with each other and if there is any deviation is found out, the system can automatically tune to bring the final product within stipulation. |
| Reinventing the service contract                  | Sensors support to determine the appropriate time for service. This optimize the time for servicing the product and minimize the service expenses for the customer. |
| Out-innovating the competition                    | With sensors entrenched in all the aspects of factory level, it creates a new opportunity for the business and increase the profit.                  |

### 4.4 Reduced Downtime

The Analysis says that downtime costs between 5 and 20 percent for a factory of its productive capacity, but nearly more than three fourths of amenities are unable to precisely estimate their total downtime cost [34]. Timely, precise and high-quality manufacture is at the core of profits. When the machine breakdown in the middle it leads to an enormous loss in addition to the traditional downtime expenses. Unexpected downtime is a worst-case situation for manufacturers. Zero downtime (ZDT) helps factories from downtime through predictive maintenance, which is a common IoT approach [35]. With ZDT, maintenance required are founded on real-time usage of the machine. Though ZDT is best known for proactive failure forecast, it has many more applications. Its capability to remotely monitor the machine’s health which allows for optimal production, for example, decreasing energy intake, improving production amount, and extending
the mechanical life of machines. Two different types of models for IoT downtime analysis is provided [36] in table 5.

**Table 5. Models for IoT downtime analysis**

| IoT in downtime | Conventional analytical models | Composite models |
|-----------------|--------------------------------|------------------|
|                 | Determines the occurrence of failure by separating the repairable and non-repairable parts based on their usage. These models influence historical time-to-failure data to detect the future failure of parts. In conditions where manufacturers do not have the privilege of detailed information from sensor data, these models are useful. | This is an advanced model where the cause for the machine failure is also predicted. This model is more advance in all levels than the previous one. |

Among these, two models the selection depends upon the availability of data. When data and information about the parts failure is available, then the first model is applicable. On the other hand when only the claim data is available, then the second model is preferred. Other factors influencing the selection of the model are the nature of parts and the stage of the parts lifecycle (initial, growth and maturity or decline). With the selection of right model, manufacturers can take their predictive maintenance to new levels.

4.5 **Informed Decisions**

Previously manufacturing industries use statistical process control and data analysis tool for optimizing manufacturing [37]. Now managers can make decisions on proactive approach and this leads to decrease in stress in decision making and increase in production and profit.

5 **Conclusion**

IoT is broadly accepted as a new technology that plays a significant role in the enhancement of the manufacturing industry. It can integrate the entire components of manufacturing sectors including sensor, processing unit, communication devices and actuation gadgets. This highly integrated smart cyber – physical systems opens the door to create a new business and market opportunities in manufacturing and paves the way for the new industrial revolution 4.0. It brings a huge opportunity in the manufacturing sector
in achieving better system performance in globalized and distributed environments. The various advances in manufacturing industry due to the implementation of IoT and their challenges are emphasized as follows:

- IoT enables the sustainable development in various sectors in industries such as reducing product miles, extending the life of machinery and equipment, preserving energy and water and enhancement of the supply chain.
- The decentralized paradigm network is required to connect all the devices with unique authentication for each node without a broker in-between.
- Multiple defensive layer, 2FA, encrypted communication, digital signature is few techniques to keep the data safe and secure.
- IoT completely eliminates the conventional method of maintenance by mere guessing from the historical data, but instead retrieving real-time data to realize the maintenance needs at an exact moment.
- IoT can help in quality improvement of product which leads to achieve reduced waste, lower costs, increased customer satisfaction and higher sales. Also, IoT can reduce the downtime cost significantly.

Moreover, the implementation of IoT in manufacturing is in the primary stage and a high research activity is in demand to enable the IoT technologies for secure, reliable operations.

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