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Role of Internet of Things (IoT) in Improving Quality in Manufacturing

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Abstract

Internet of things (IoT) is being increasingly utilized in manufacturing where machines, devices and humans are connected and can communicate through the internet or the other wireless technologies at time and place. Quality represents a very important attribute of any system. Whether the quality is interpreted as the conformance to specifications, inverse of variability, or any other interpretation (like those related the satisfaction of customers or even having zero or almost zero defects), IoT can play an important role in improving this quality in manufacturing. Therefore, in this work, an overview of the application of IoT in manufacturing including advantages, issues and challenges, benefits and required enabling devices and technologies will first be shown. Then, an overview of quality as an important attribute of manufacturing systems will be presented and explained. Also, the work will show how IoT can play a pivotal and important role in improving the overall production quality in any manufacturing plant. This improvement of quality can be realized and will be in more than one form including the form of eliminating waste and deficiencies in products and also production processes, as well as in reducing cycle time and increasing the throughput and effectiveness of manufacturing systems.

Keywords
Internet of Things (IOT), Manufacturing, Waste Elimination, Cycle Time and Quality Improvement

Introduction
Throughout the last few years, Internet of things or IoT has been emerging continuously where things and humans are connected, can communicate over the internet or the wireless world and are uniquely identifiable (Alothman et al. 2018). This concept of IoT can be traced back to the early 2000s as K. Ashton was working on linking radio frequency identification or RFID data to the internet at the AutoID lab at MIT (Lopez Research LLC 2013) .

With the use of IoT, customers are better engaged (Alothman et al. 2018) through the unique and continuous interaction between people (employers, employees and customers) and the systems (manufacturing system for example) which can virtually happen anytime and anywhere. Additionally, by utilizing IoT and the corresponding technologies, wastes can be reduced resulting in a better management of resources (Tutorial Point 2016). However, IoT has also some shortcomings including privacy and security (Rose et al. 2015 and Tutorial Point 2016). The introduction of IoT introduced a third dimension to the communication systems which is the “anything” dimensions which is added to the previously well known two dimensions of “anytime” and “anyplace” making it possible for all

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types of communications, namely, human to human, human to things, things to things and computers to computers (Tan and Wange 2010 and International Telecommunication Union (ITU) 2012).

Manufacturing is considered as the most important of application of IoT. Other areas include healthcare, energy, transportation, infrastructure and education (Tutorial Point 2016). When it comes to IoT, related technologies include artificial intelligence, networks, sensors (Tutorial Point 2016). with radio frequency identification or RFID and wireless sensor networks or WSNs as being important enablers of IoT (Tan and Wange 2010 and Bi et al. 2016).

Quality is a very important aspect of any process or a product (goods, services or software (Gryna 2001)) including manufacturing processes. The word quality has several definitions but some of the most important are (Montgomery 2005, Gryna 2001, Kolarik 1999 and Crosby 1980):
a. Fitness for use including quality of conformance and quality of design
b. Being inversely proportional to variability
c. Satisfying customers needs and expectations (loyalty of customers)
Durability, reliability, being user friendly, ease of maintenance, being free of defects, serviceability and availability are some of the required or preferred features in manufacturing products, while the freedom of all types of waste and inefficiencies represent represents aspects required for a high-quality production or manufacturing processes (Montgomery 2005 and Gryna 2001).

Thus, it is very important to understand the critical role that IoT can play in improving quality in all aspects of manufacturing. This will represent a very useful guide for researchers and practitioners to help them identify the areas of improvement in their manufacturing processes regardless of the nature of these processes while at the same time allowing them to apply IoT in the most efficient way.

1.1 Objectives

Objectives of the research include the following:

a. To give a clear introduction about the concept of IoT in manufacturing.
b. To highlight some of the benefits, challenges and issues associated with the application of IoT in manufacturing.
c. To review the concept of quality in connection with manufacturing.
d. To present a clear understanding of the role IoT plays in improving quality in the field of manufacturing.

2. Literature Review

2.1 Manufacturing Industry Developments:

It is a well known fact that manufacturing plays an important role in every single industrial country. For example, according to the National Institute of Standards and Technology, 10.8% of the total United States GDP was from manufacturing (National Institute of Standards and Technology 2021). The major advancements in manufacturing can be traced to multiple factors and one of the most important among these factors is the in information technologies. An example of such technologies is the Wireless Sensors Networks or WSNs that utilize sensors and sensor nodes (basically) everywhere allowing for top measurements, data recording, computation and communications. With the utilization of such technologies, IoT comes in place along of all of the associated capabilities that are able of transforming manufacturing technologies all over the world while allowing for new manufacturing models like the cloud manufacturing models (Bi et al. 2016).

2.2: IoT and Manufacturing:

When IoT is utilized in manufacturing, objects (things), systems and people are connected through the internet (Sinha 2021) leading to the improvement in both efficiency and productivity (which sometimes is referred to as smart manufacturing with the argument that smart manufacturing is related to data collection and analysis not the internet (Ezell 2016). Systems can be upgraded to have IoT capabilities or can just be IoT ready. IoT enablers include advanced technologies like cloud computing, WSNs, and gateways. Big names in manufacturing are already (and have been) using IoT in manufacturing like Microsoft, Intel, IBM, Cisco and General Motors (Greenough 2016, Kagermann et al. 2013, Kanbayashi et al. 2016). Just to give an idea, about 11.3 billion connected devices were used globally in the year 2020 and an expected 12.7 billion in 2021 although there was a shortage in the chips and the entire supply chain

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due to the COVID situation (Sinha 2021). This number is expected to increase to 14.5 billion devices by the end of 2022 and it is also worth noting that the IoT industry growth rate was 22.4% in 2021 (Wegner, 2022). A well known and related concept is the IIoT or the Industrial Internet of Things which "implies the use of sensors and actuators, control systems, machine-to-machine, data analytics, and security mechanisms" (Mourtzis et al. 2016).

This does not only include manufacturing processes but also the management (supplying and receiving), communication with customers and data management while assuring the highest level of quality (Axiomtek Co. Ltd 2015). This IIoT is playing a major role in the fourth industrial revolution (which is dependent on big data produced by applying IoT in manufacturing ((Mourtzis et al. 2016 and Kagermann et al. 2013) or as called Industrie 4.0 in Germany or "China Manufacturing 2025" (Kanbayashi et al. 2016). So, it is clear that major global industrial powers are competing in the IIoT field which represents a strong driver to the significant advancements that we have been seeing in the last few years (Alothman et al. 2018). As mentioned above, utilizing IoT in manufacturing results in huge amount of data which is commonly known as big data. This big is not only big in terms of volume (size) but also in terms of velocity, variety, veracity and value making the well known 5 Vs of big data (Kin and Kaynak 2015). Quality can be achieved by taking advantage of the big data which become available with the increased use of IoT in manufacturing. While improving quality and reducing or even eliminating errors, this can also reduce manufacturing cost and help in the management and planning of the entire supply chain (Kin and Kaynak 2015). Despite all of advantages associated with IIoT in manufacturing, some serious disadvantages are present including security, safety, privacy, being prone to major cyber attacks, uncertainties in the return on investment and the continuous loss of jobs especially on the floor due to the increased utilization of technology (Alothman et al 2018, Tutorial Point (1) Pvt LTD 2016, Greenough 2016, Jenkins 2017, Jinushi 2014, Reddy 2014 and Axiomtek Co. Ltd 2015).

3. Role of IOT in Improving Quality in Manufacturing: Discussion

3.1 Quality and IoT:

When it comes to utilizing IoT in manufacturing, it is important to be able to capture useful data and then get the most out of this data (Alothman et al. 2018). By doing so, a lot of things can be improved like overall equipment efficiency or OEE, cycle and lead time, reliability, availability and costs including energy costs. Thus, when IoT is adopted, then the entire manufacturing system can be improved by achieving better visibility of all of the manufacturing processes, longer life of the equipment, reduced costs, improved flexibility and reduced environmental pollutants like in the case of "eco-industrial park" where pollutants and wastes are reduced with an efficient resources sharing (Jenkins 2017, Kagermann et al. 2013, Reddy 2013 and Pan et al. 2015). As mentioned above, IoT can improve availability of systems and machines. This is achieved through the efficient use of the data (specifically big data) that result form IoT utilization leading to a reduced downtime for these systems and machines. Costs can be reduced in this direction by having good failure predictive systems that take advantage of IoT capabilities which clearly is more efficient that just being reactive to failures and unavailability of system due to these failures. For example, adopting IoT in manufacturing can cut costs (development and assembly) by up to 50% (Mourtzis et al. 2016). IoT also helps a lot in terms of achieving a better overall management of the entire supply chain including scheduling which clearly can lead to reducing costs (Axiomtek Co. Ltd 2015).

3.2 IoT in Manufacturing and Quality Improvement:

There are different manufacturing attributes that include for example, quality, effectiveness, cycle time and throughput. Quality has different definitions; it can be defined as the fitness to be used, the satisfaction and loyalty of customers or the specifications conformance. Quality can also be defined as being inversely proportional to the variability in processes and products. Quality includes two elements: one is the features of products and the other is the freedom of defects. In manufacturing, the features include things like performance, reliability and durability, easiness of use, reputation of the product or the company or perceived quality, the appearance and serviceability while the freedom of defects indicates that the product is free of defects at all stages and that the production processes are free of waste activities like rework and redundancy (Montgomery 2005 and Gryna 2001). The cycle time is time one unit spends while being processed or assembled or the time difference between one unit starts processing and the next unit starts.

Cycle time includes the production operation time and the part and tools handling times. For a production line, the cycle time is the summation of longest processing or assembly time and units transfer time (Groover 2008). Cycle time is also defined as the time that a part spends as a work in process or WIP where WIP is all the inventory between beginning and end points of a process. The throughput or throughput rate is the average output per unit time for a

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process, workstation, machine, production line or a plant. In other words, it is the average quantity per unit time of nondefective parts produced (Hoop and Spearman 1996). The effectiveness of a manufacturing process is ability of these processes to produce the intended products with specified high quality within a specific period of time with a minimum amount of product and process waste. With internet of things or IoT, all things are connected through the internet where they are identifiable and can communicate with each other. It represents an emerging concept and a set of very advanced technologies. IoT can be applied in different fields and one of the most important of these fields is the manufacturing. In manufacturing, IoT can be utilized to have all the objects one the shop floor, production systems and people at all levels connected. Sensors and wireless sensor networks are used to send and receive data anytime at anyplace. Information and cloud technologies and big data analytics in addition to these networks are important components of the application of IoT in manufacturing (Shariatzadeh et al. 2016 and Tutorial Point (1) Pvt LTD 2016). IoT adoption can save a lot of money for companies. For example, it is expected that a cost reduction in products development and assembly costs of as much as 50% can be achieved by manufacturers by the using big data analytics (Yin and Kanyak 2015) which might be considered as a result of IoT use.

Cutting costs while having an improved quality helps also in increasing customers' satisfaction. In addition, with this big data available, the downtime for machines can be decreased as a result of the predictive maintenance achieved by IoT. The failures can be predicted before the need to entirely shut production off making it easier to act quickly. Also, better planning and management of the shipping and scheduling processes by the use of IoT also helps in cutting the overall production cost (Axiomtek Co. Ltd 2015). This helps tremendously in increasing the available work times and also the customer satisfaction leading to better overall quality and production throughput rates and effectiveness. Also, an important feature of adoption of the IoT is that the final products can be capable of collecting and sending data about their state and history as they are being used (Mourtzis et al. 2016 and Yin and Kaynak 2015) as was mentioned earlier. This helps in quickly adjusting production processes if issues occur with these products and in dealing directly with consumers as problems appear. This in turn will lead to better design and production planning while at the same time increasing customer satisfaction.

IoT can play an important role in improving manufacturing systems. It can improve the overall effectiveness, quality, the production cycle time, throughput and other attributes. When it comes to quality, IoT helps in producing products are conforming to the required specifications with minimal variability or in other words, products with better quality. With IoT, sensors are used to continuously taking measurements of the quality characteristics and sending this information using the networking capabilities of IoT. Thus, production processes can be monitored in real time from anyplace and at anytime allowing for a better control and for the ability to adjust processes quickly and effectively. This in turn results in minimum variability in the things being produced which means a better quality as quality is related inversely to variability as was mentioned earlier. This real time monitoring allows also for having an almost error free manufacturing leading to a better quality production. Errors in manufacturing operations always represent a problem that affects performance, quality and effectiveness. The use of IoT in manufacturing can lead to a big reduction in errors at all stages through the active tracking and monitoring of the processes. As an example, a Fujitsu Group company reported a 70% reduction in errors by applying IoT solutions in their plant (Kanbayashi et al. 2016).

Reducing errors results in more effective operations, better performance, increase in the active working times and throughput and ultimately better quality. In addition, with the advanced connectivity and networking capabilities offered using of IoT, the customers themselves can participate in the overall production processes. Using IoT, customers are transformed from being passive as in the traditional ways to be active participants resulting in a much better engagement (Tutorial Point (1) Pvt, LTD 2016). They can view their orders as they are being processed which gives them the ability to be actively involved. This is an important thing that can be achieved by the application of IoT as it results in a high customer satisfaction which again means a better quality since customer satisfaction is an important aspect of quality. Thus, the application of IoT in manufacturing can effectively improve several aspects of quality some of which are shown in figure 1 below.

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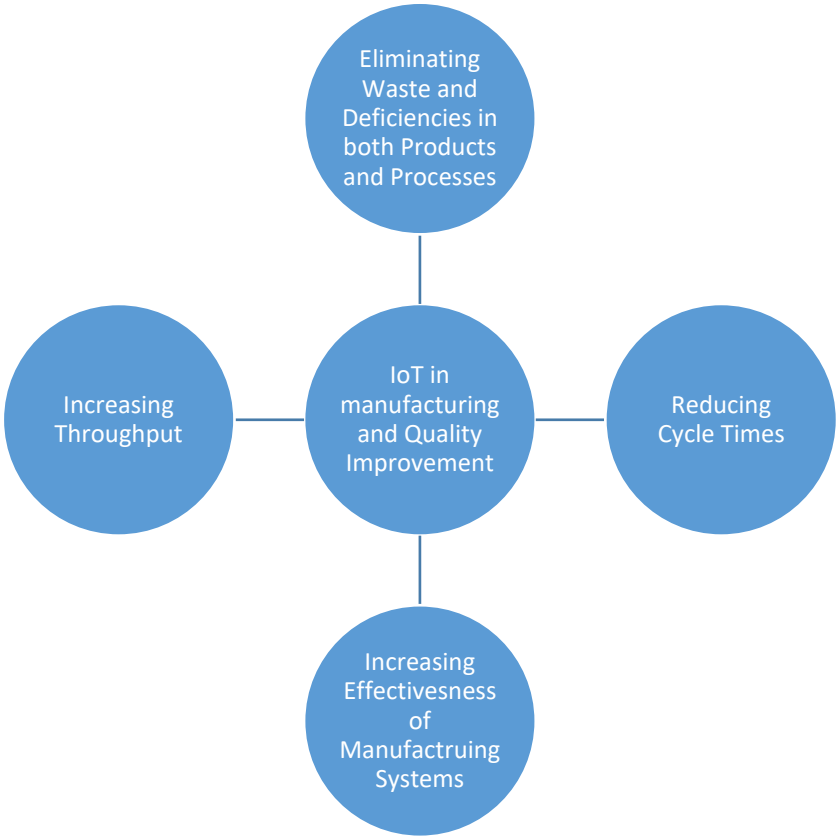

Figure 1. IoT in manufacturing and quality improvement

Big data amounts available by using IoT can be very effective in improving manufacturing. As mentioned earlier, this data about the parts specifications and the production processes themselves is being captured, transmitted and analyzed continuously with the advanced technologies offered by IoT like information and cloud as well as the virtual reality and graphical interfacing technologies. Although current analytics provide good data analytics, IoT offers real and direct information that leads to better resources management (Tutorial Point (1) Pvt, LTD 2016). This results in a live view of the production processes and allows for the people involved to quickly identify the areas that might be causing any delays, wastes, work in process inventories or processes that not performing extremely well and then intervene and correct that as soon as possible.

Thus, all the unnecessary or incorrect operations will be eliminated or minimized. In addition, production line balance can directly be modified as needed. As a result, the overall effectiveness and performance of the production processes will be improved. In addition, the cycle time will be reduced and throughput will increase while at the same time achieving the specified quality requirements. So, it is clear that IoT can play a pivotal role in improving the overall production quality, in eliminating waste and deficiencies possibilities in the products and in the production processes, in reducing the cycle time and increasing the throughput and effectiveness of manufacturing. Yamanshi factory (A Fujistu company that produces networks products) can be taken as another example of IoT capabilities in improving quality and efficiency in manufacturing. Their system has three features; firstly: big data generation and processing before that arrives to the clouds, secondly: making this data available (securely) on the cloud, and finally the production status and data visualization in real time (Jinushi et al. 2016)

4. Conclusion and Future Research Areas:

Manufacturing industry represents a major sector for all of the industrial countries all over the world which makes it essential to continuously improve the methods, products and processes in any manufacturing field. In the last few years, one of the most emerging technological advancements is the introduction and adoption of the Internet of Things or IoT. IoT is basically and emerging and evolving concept that is continuously growing with a lot of potential and

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advantages that some of which is yet to be revealed. With IoT, everyone and everything can communicate everywhere at any time opening the way for a huge number of possibilities. Some of the most important enablers of IoT are the Wireless Sensors Networks (WSNs), advanced information technology systems and cloud capabilities. While IoT is applicable and can be adopted in several fields, manufacturing represents one of most important areas.

Quality is a major aspect of any manufacturing system which means that it is always critical to achieve very high levels of quality and continuous improvement. Quality can be defined as freedom of defects, being fit for use (conformance and design), inversely proportional to variability and also reputation and customers satisfaction. Quality of products and processes can be improved tremendously through the successful and effective use of IoT in manufacturing. In fact, this can lead to quality levels that probably were not even possible before the introduction of IoT in manufacturing. Adoption of IoT in manufacturing results in a reduced numbers of defects. In fact, this number of defects can be reduced to (or almost to) zero which is clearly an important aspect of quality. In addition, IoT application in manufacturing can play an important role in reducing cycle time and tremendously increase throughput of basically any manufacturing system. On another front, IoT in manufacturing can also lead to an improved efficiency and reduced amounts of waste (regardless of the type of that waste) in the processes themselves. This clearly can lead to significant improvements in quality, quality control and assurance.

Given that IoT is still in the phase of evolvement and increased utilization overall the world, it is necessary to have more research in this area in general like for example the area of information and cloud technologies, issues and challenges including security and privacy and the effective use of IoT everywhere. It is also very important to have a lot of research in the area of the effective adoption of IoT in manufacturing especially in the area of making current equipment and machines to make them IoT friendly; i.e. the ability to upgrade existing systems to have IoT capabilities. In addition, significant research is needed in the area of quality control in manufacturing and to be specific in the possible ways of transforming quality control aspects to go hand in hand with the very quick developments in IoT in manufacturing. In other words, some of the well known concepts and theories of classic quality control (which are absolutely needed all the time) need to be modernized to take full advantages of the all of the new and highly effective IoT data collection and processing techniques. For example, quality control charts and acceptance sampling techniques should be connected and should benefit of what IoT has to offer. At the same time, quality control engineers, technician should be trained well on the effective use of IoT in their fields. Also, quality control courses in universities can be updated to make students fully aware of improvements that are going in current real life manufacturing.

This clearly means that a lot of research is needed to achieve this in companies and universities. Also, research in the area of lean manufacturing is absolutely needed. As was mentioned in this work, IoT adoption in manufacturing leads to reduced amounts of waste in manufacturing processes and this reduction is basically lies in the heart of lean manufacturing. So, the research opportunities are very obvious in this area. Finally, quality control connection with the area of operations research is something to heavily investigate. Operations research is absolutely needed to have an effective application of IoT in manufacturing given all of data and optimization requirements of IoT. This means that research that takes into consideration the development of new quality control techniques in parallel with operations research is a rich area of future research.

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