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An Investigation of Smart Manufacturing Using Digital Thread and Digital Twin Technology for Enhancement of Product Life Cycle

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Abstract: ***The paper basically deals with the challenges that are faced by the Traditional manufacturing techniques that could not meet the requirements that are required in development of the product life cycle in these modern days which are fulfilled by the Smart manufacturing. The challenges faced by the manufacturers such as shortened Product life cycle, Increased customer-oriented value, Sustainable development of the product and Global competition. Such factors affect the traditional manufacturing techniques that had been followed for years. In order to cope up with the emerging trends in the product development the Smart Manufacturing has envisioned as a good approach to tackle these problems. The evolvement of the Industrial Revolution from Industry 1.0 to Industry 4.0 has led to the emerging principle of the Smart manufacturing. The smart manufacturing is referred to as synergistic integration of Computer oriented manufacturing which involves multiple users, systems and technologies of data processing. It has the ability to make its decisions, Highly adaptability and fast design changes along with flexibility of technical work force training. The concept of Digital thread and Digital twin plays a major role in the Smart manufacturing. The smart manufacturing holds key technologies such as Big data, Edge computing, Middleware, Augmented reality, Smart Sensor technology and Advanced robotics. This helps in optimization of the product life cycle development and supply chain operations by setting up a smart factory which has interoperable systems.***
Keywords: Smart Manufacturing, Digital Thread, Digital Twin, Middleware, Big Data, Smart Factory

I. INTRODUCTION

The manufacturing process deals with the conversion of raw material into finished product under several sequence of operations. The manufacturing process are involved in many sectors which are based on the product development for example Chemical industry, Electronics industry, Metal processing industry, Metal machinery industry etc. In the recent years the manufacturing industries have undergone several transformations in the technological development in the field of Automation, Computerization and Data processing. The impact of this digitization in the manufacturing industry has led to the development of the smart factories and smart manufacturing techniques. This has enabled to develop new methods and tools to support the production and product development cycles. The industrial revolution has revolutionized to automate the factories to shorten the product life cycle and to increase the production. The early start of the industrial revolution has made industries to mechanization of the factories which the paved way for the mass production of the products followed by the automated production which involved the use of robots and automated systems in particular work units and led to the next stage of Industrial internet of things which has developed a concept of Smart factories and Smart manufacturing which enabled the interoperable systems. This paved way for the more reliable and intelligent manufacturing operations.

As the future of manufacturing is geared towards customer specific products and materials it has made to ensure the short product life cycle, Quick delivery of the product, Zero defects, Efficient manufacturing with available resources. Smart manufacturing has enabled to meet the following criteria to the increasing customer demands and tackle the issues in the manufacturing process that is present in the traditional way of manufacturing. The smart manufacturing has brought the concept of intelligent machining and gained impetus breakthrough in the technological development that has took the product development to the next stage. The key technologies involved in the smart manufacturing includes the Digital thread and Digital Twin techniques which has enabled the product life cycle process much easier by allowing the flow of information from one system to other in order to operate as an interconnected system which has an advantage of reducing the lead time of the product development cycle and manufacturing much simpler. The digital thread has enabled to operate the factories in an efficient way by providing a communicated framework of flow of data form one system to another in an integrated way and allows a connected data flow and integrates view of asset's data throughout its lifecycle across traditionally siloed functional perspectives. It raises the platform for delivering "The right

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information to the right place at right time". It delivers the methods and protocols as framework to transfer data between design, manufacturing, quality, operations and product support processes which helps in integration of smart manufacturing system. In the same way the digital twin also plays a vital role in the designing stage of the product life cycle process. The digital twin technology helps in the formation and simulation of the digital replica of the living or non-living entity which refers to the replica of the actual physical twin and potential processes, system, place, people and devices indented for various purposes. The enables to process and simulate the product which has to be manufactured. This technology enables to shorten the lead time, reduce the wastage, increase production, optimize the product life cycle development and the supply chain of the production process. Other key technologies involve Big data, AI, Design tools, Middleware, Edge computing, Augmented reality etc. This enables the manufacturing processes to accelerate the process of design to production timeline at reduces cost.

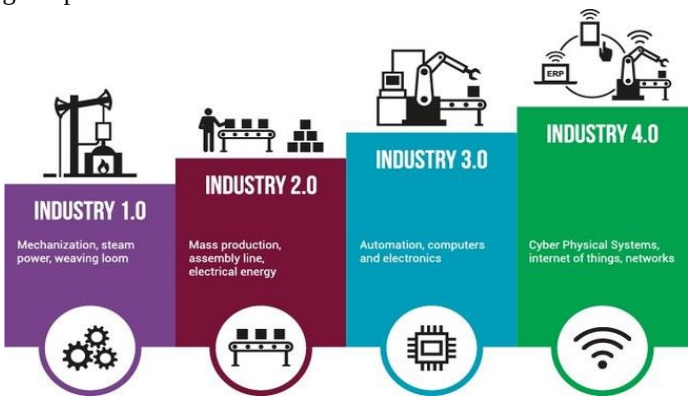

Figure.1. Industrial Revolution stages

II. OVERVIEW OF TRADITIONAL MANUFACTURING

The term manufacturing deals with the production of products for use or sale using labour and machines, tools and chemical or biological processing and formulation. It is the way of transferring the raw materials into finished goods or products that are required to satisfy the needs of the society. In the early 1800s it has started off from a small-scale production line of crafts and goods which have then evolved into a large mass production. The early 2000s is the era where the computerized and personalized manufacturing systems came into functions for mass production which can be termed as the Industrial revolution 2.0. manufacturing processes involving a group of activities in converting raw materials into finished products. The processes involved are selection of raw materials, production of objects, assembly of parts, inspection, despatching etc. This process has coined into a term called Supply Chain management process of the organisation. The manufacturing process includes foundry, forging, heat treatment, painting etc. This involves the use of resources that makes to meet the delivery, cost, quality and optimal economic goals in limited conditions. These processes mainly involve mass production and heavy energy consumptions such as coal or electricity.

The traditional or conventional manufacturing process consumes lot of energies, especially for production and utility. They also produce a lot of pollution and add to deterioration of environment. Due to these effects, the manufacturing companies are gradually transforming their manufacturing systems from traditional mass production to flexible lean manufacturing systems. Because of the rapid changes in technologies, the manufacturing systems itself is constantly changing and evolving. This has led to the development of the cleaner manufacturing processes. In order to reduce the environmental damage due to the manufacturing, this has led to the change over of the new manufacturing process.

In the recent times, two types of manufacturing techniques have emerged emphasizing waste elimination. They are Lean manufacturing and Green manufacturing that emphasized of waste elimination. In lean manufacturing it employs several techniques to reduce all types of waste in the production systems. In lean manufacturing concepts the waste has been classified into 8 categories that has to be monitored. They are Overproduction, Waiting, Inventory, Transportation, Motion, Work force, Over processing and Defects. This has led to the implementation of smart manufacturing in industries. Smart manufacturing will transform traditional manufacturing from reducing cost operations by value added operations thus increasing competitiveness. This acts as a value creation process from design to production, logistics and service.

The smart manufacturing is shifting from knowledge based smart intelligent machining to data driven and knowledge enabled smart manufacturing process. In this big data and data analytics plays a major role in converting data into value insights to assist in decision making. This has led to the development of concept called Digital thread as data flow network to provide communicated framework in smart manufacturing.

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III. FEATURES OF SMART MANUFACTURING

Smart manufacturing is gaining popularity all around the world and increased a competitive edge among the manufacturers in enabling to produce the product with shortened life cycle and reducing the waste. The term smart manufacturing has been coined by several agencies in United States and increasingly used all around the world by the manufacturers. There are many initiatives in the smart manufacturing such as Industry 4.0, Smart factory, Intelligent manufacturing, Cyber physical production systems and Advanced manufacturing. The smart manufacturing is characterized based on the integration of integrated Information Communication Technology (ICT) and manufacturing industry. This had led to the connection of real physical world and virtual network world using the integrative Cyber Physical Systems (CPS). The smart manufacturing incorporates several technologies such as Cyber Physical Systems (CPS), Internet of Things, Robotics/Automation, Big Data analytics, Cloud computing, Artificial Intelligence, Smart Sensing and Cognitive Technology.

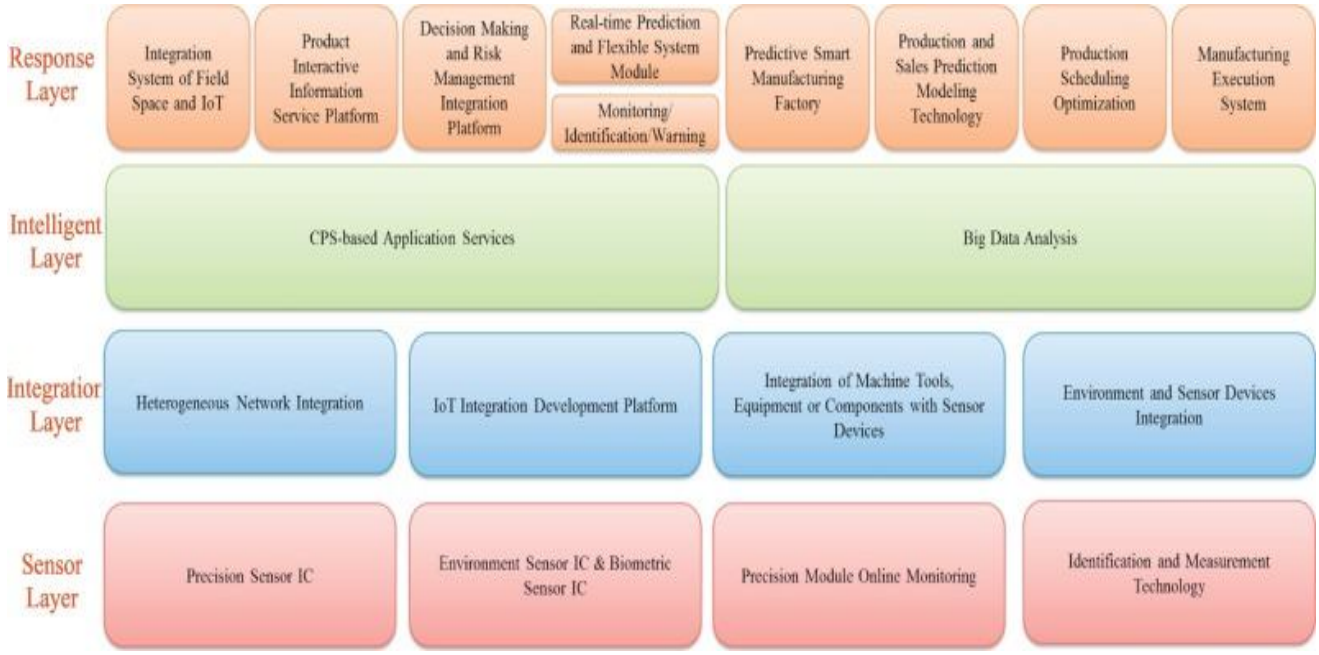

Figure.2. Key Technologies in Smart Manufacturing

These technologies have made the manufacturing digitalization in smart manufacturing systems. Bringing valuable opportunities to manufacturing industries by providing a new way to carry out the smart production and precision management. This makes the manufacturing systems smart. Cyber Physical systems have become a key technology in smart manufacturing. It consists of physical systems such as machines, workpiece, vehicles etc. which are equipped with technologies such as RFIDs, Sensors, Microprocessors, Microcontrollers, Telematics and Embedded systems.

The other technology which has gained an immense popularity is the Internet of things which has enabled to provide the source of wireless connectivity of machines, devices and things which allows the devices to be monitored and controlled over a communication network. This has created a solid foundation for the cyber physical systems integration by providing great potential in device communication, connections and data collection. This evolved as a key in the development of digital thread which acts as a communicated framework of network of data flow process in the smart manufacturing systems.

The digital thread has helped in connecting the digital information through product design, manufacturing and inspection process of making a product. It offers a formal model of regulated interaction systems regarding technical and built information. It curates the data from different systems throughout a product's life cycle time and turns into valuable action data. This gives the product cycle with its design, procurement process, test and evaluation, generation, field operation and sustainable functions. The smart manufacturing is considered as the fourth revolution in the manufacturing which has its own identity in the following pillars of it. They are Manufacturing technology and processes, Materials, Data, Predictive Engineering, Sustainability, Resource sharing and Networking, Improved efficiency, Risk reduction and agile decision-making ability.

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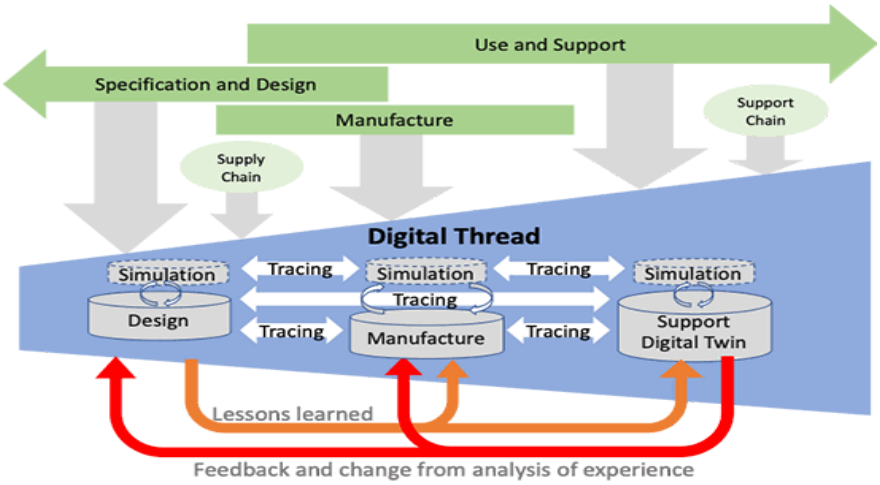

Figure.3. Architecture of Digital Thread Technology

Smart manufacturing involves the Data acquisition activities such as data collection, data management and data analytics which provides real time actionable information required to build intelligent systems into manufacturing operations. Smart manufacturing always involves the use of available resources in the right form by the right people with the right knowledge along with right technology under right operations.

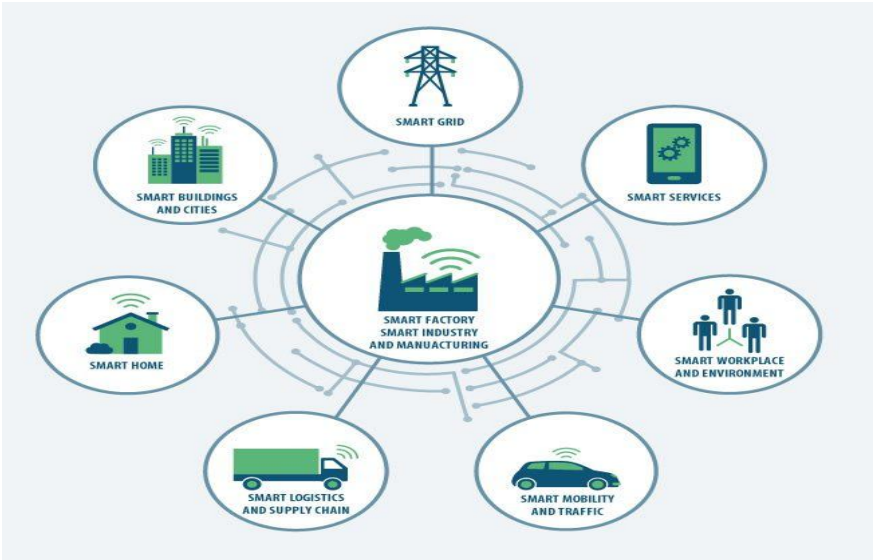

Figure.4. Interconnection of Smart manufacturing systems

The smart manufacturing systems covers four major areas. They are Smart parts, Smart machine, Smart production life and Smart Factory.

A. Smart Parts

The sensor technology is used to the components so that they can possess self-sensing capabilities of sensing temperature, vibrations and other physical parameters that can be sensed and act according to the environment by taking decisions on its own without any human interventions. This can be able to improve the reliability and service life of the systems.

B. Smart Machine

This system collects the information of the operating status of various parts involved in the process, conduct Big data analytics and detect the abnormalities in the system as early as possible.

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C. Smart Production Line

The machines on this type of Production lines can communicate and support with each other machine along the production line to operate in a concurrent approach by sharing the data of the manufacturing operations to be performed and thus contributes to the production efficiency.

D. Smart Factory

This system is linked with the consumer needs and provide customized services. The internet is used to link the systems between factories to control the production schedule of the products.

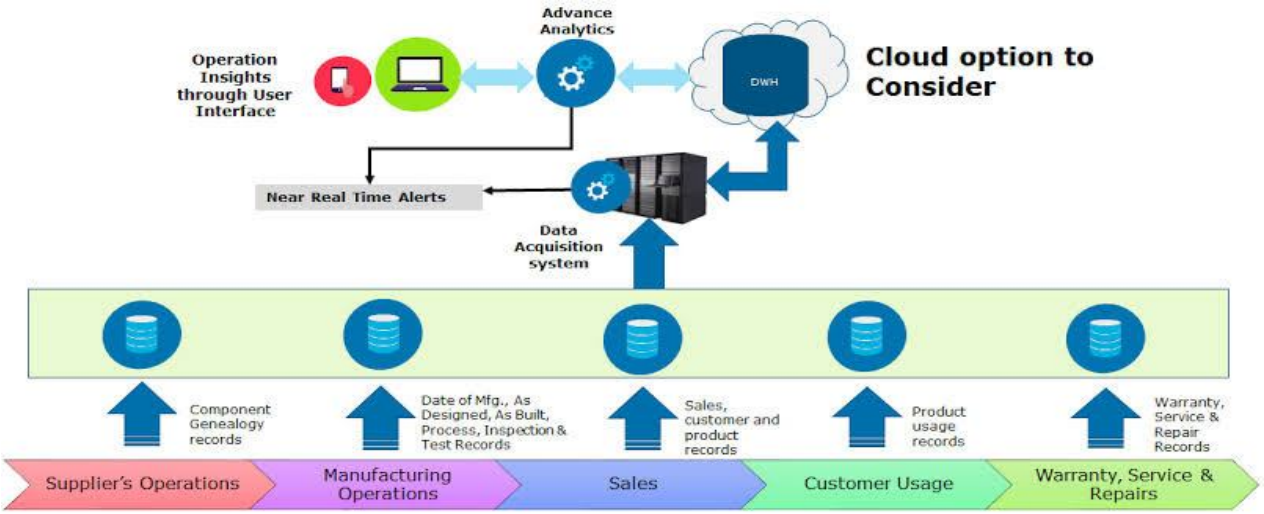

Figure.5. Architecture of Smart Manufacturing System

IV. GOALS OF SMART MANUFACTURING

In the modern days, many manufacturing industries seeks competitive edge through convergence with cutting edge of Informative Communication Technology (ICT). Smart manufacturing deals with the collection of technologies that acts as a support system for accurate and effective engineering decision making in real time applications. Industries have begun to embrace the model-based enterprise paradigm, though there may be challenges in the gaps of integrating digital data through standards and in building tools to data for decision making throughout the product life cycle. The goals of the smart manufacturing systems includes Fostering of technological and economic growth, Build a platform which is customer agile, Available of resources whenever required, Creation of required workspace and workforce, Improve safety standards, Sustainability in the industry, Energy reduction, Reducing waste streams in the manufacturing operations and seamless interoperation of the manufacturing systems which allows for plug and play configuration. These goals can be achieved by the allocation of plan for each operations like Identification of common information which integrates product life cycle, Promoting and promulgating standards for representing information, Define and demonstrating framework and technologies that support the system in life cycle and finally defining and demonstrating the mechanism which provides feedback cycle from stages of operations back to design. This will enable to design effective products, processes and systems in less time and enables to communication in an interacted way thus reduces the defects and problems.

V. APPLICATIONS

Some typical applications of the Smart manufacturing include:

A. Smart Machining Operations

In the smart manufacturing, the intelligent or smart machining can be done with the help of smart robots and various types of smart objects and techniques an be employed which are capable of real time sensing. Products can be produced by the CPS enabled smart machine tools which has the ability to capture real time data so the machine tolls and services could be synced to provide smart manufacturing process. There are various sensors and devices that can be used to gather the real time machining data which can be done by the machine tools.

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B. Chemical Industry

This industry can employ smart manufacturing systems which can be incorporated for producing the chemicals and pharma related goods with some targeted final properties. The smart manufacturing in the chemical industries should not be employed to maximize competitiveness in economic growth but also should be able to reduce the safety incidents.

C. Semiconductor Manufacturing Industries

The semiconductor manufacturing technologies have become the major target of the consumer electronics market. As there has been a shift in technological advancement there has been a major blow in the semiconductor manufacturing technologies which has become more and more complicated and it has become a tough state to maintain their production yields. The smart manufacturing has provided a platform which has been designed to improve yield enhancement and assurance.

D. Energy Systems

The energy sector has grown a long way to overcome the depletion of natural energy sources and replace them with the alternative energy sources. Fuel cells has gained a popular sign in these modern days and providing a great source of energy in various fields of operations. Fuel cell vehicles which utilize alternate fuels such as hydrogen to power the electric motor of the vehicle by producing onboard electricity. The Department of Energy (DOE) has created a route sheet to set some targets of hydrogen storage which involves the operating limit of temperature, refuel rate of hydrogen storage system. In this aspect, the smart manufacturing technology can be put forth the operating challenges in the hydrogen storage in the metal hydride.

VI. BENEFITS AND CHALLENGES

In these modern days, the manufacturing technologies has become smart to reduce maintenance cost, improved machine utilization, digitized process and operations, centralized data, smart systems, connected factory operations, smart and intelligent products and various other aspects have been improved by the employment of smart manufacturing systems in the product development life cycle. Smart manufacturing will help in transforming how the products should be designed, fabricated, operated and used. In today's market which is based on customer-oriented value, smart manufacturing has technologies to create highly differentiated, cost efficient and competitive products that has the ability to meet the modern-day market demands in a short span of product life cycle and increased profit sales. In order to gain a competitive edge, industries must be able to shift to smart manufacturing facilities and technologies to deliver the right products at the right cost at the right place and at the right time. This can make industries more efficient, profitable and make them sustainable in these modern market trends. The add on benefits of the smart manufacturing involves the energy redundancies, zero defects, faster technologies and adoption of the product according to the environment it is build to perform its indented functions. By following this most companies will be able to see a Return of Investment (ROI) on their investments within a short duration of time period through increased efficiency of labour, materials, creation of new jobs and having more reliable results. Even though there are many benefits in the SM techniques there are quite some challenges as well. The major drawback is the bottleneck in the smart manufacturing technologies is achieving the communicated and integrated framework between physical and virtual spaces of manufacturing. It cannot be adopted independently. The workforce spills gap that has been generated due to more connected and integration of manufacturing systems should be addressed and given a top priority in the organisation planning to adopt smart manufacturing. The cyber security of the physical systems plays a major role in the smart manufacturing technology.

VII. CONCLUSION

This paper proposes the idea of implementing the innovation technologies involved in the smart manufacturing for the enhancement of the product life cycle and the optimization of the supply chain of the production. In this type of manufacturing process, huge amount of data is produced and analysed to obtain efficiencies and reduce defects in the manufacturing process. It has been confirmed that implementation of Digital thread in the smart manufacturing process and setting up smart factories increases the supply chain efficiency by 15.66% which enables the delivery of new product to the market at a very faster rate of about 25%. The digital twin has facilitated the digital thread which has made the manufacturers to understand the operations of tasks of the production run on the shop floor before the start of the operation. This has enabled to reduce the defects by detecting it before the stage of manufacturing the product and reduce expensive waste. On an average the implementation of the digital twin reduces defects of about 11 per million which enables to achieve a perfection rate of about 95% in every operation. This has enabled the processes to be done in a much simpler fashion and ensured maximum expenditure efficiency with the application of Digital manufacturing.

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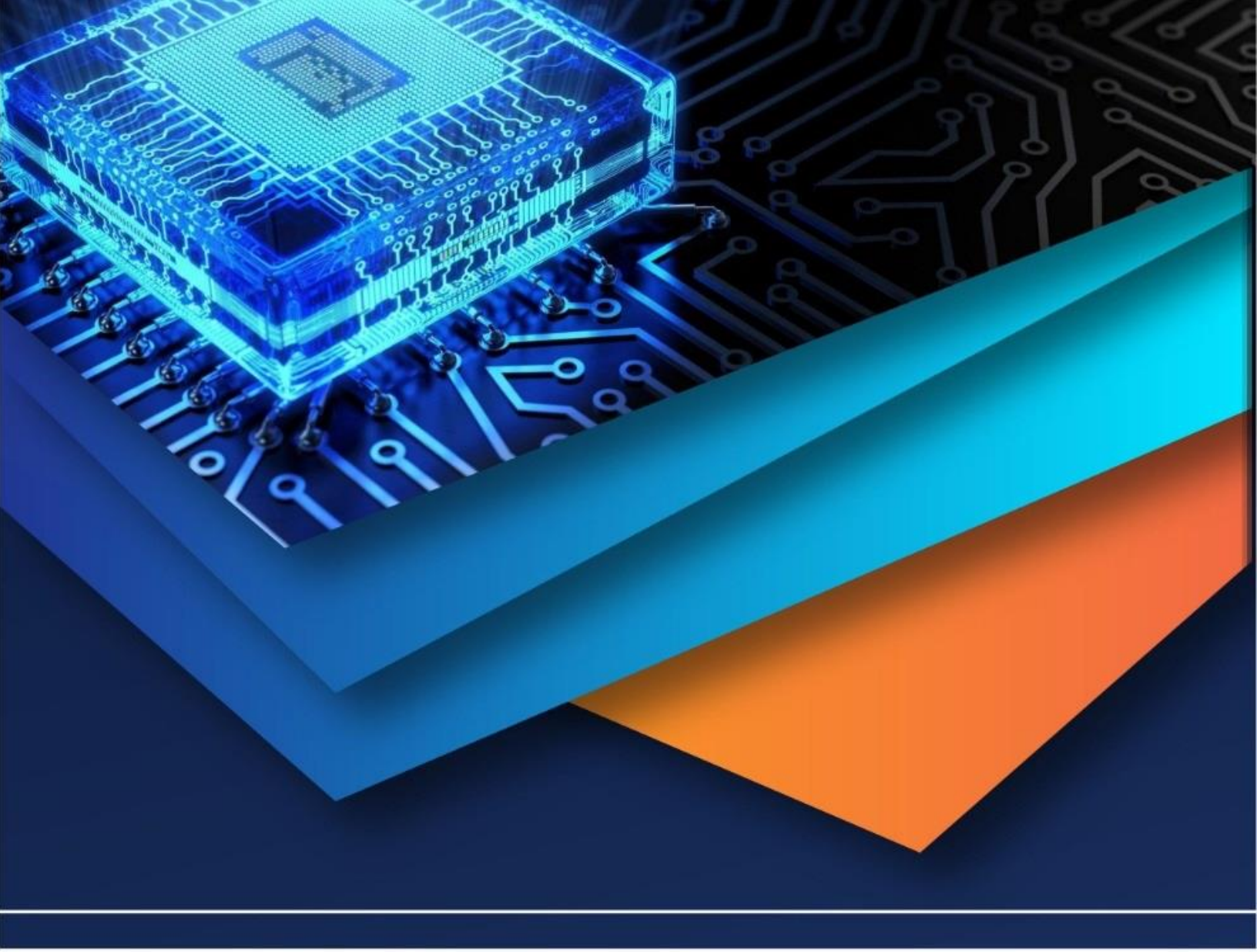

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