DIGITAL TWIN AND ITS ROLE IN INDUSTRY 4.0

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Abstract - This paper reviews the relevance of Digital twin technology in ongoing fourth Industrial revolution, generally known as Industry 4.0. In Industry 4.0 many new technologies are introduced to make the manufacturing process more efficient and various process are being digitalized. This paper talks about the advancement of Industrial processes through the help of Digital Twin technology. This technology is one of the enabling technologies of Industry 4.0 among other ones. Enabling Technologies for Industry 4.0 alongside digital twin are also mentioned in this paper. This paper talks about implementation of digital twin in industry 4.0 for predictive maintenance, continuous optimization of production processes and continuous processing of its data. This paper focuses on application and implementation of novel technology like digital twin in industry 4.0. Despite being novel concepts Digital Twin and Industry 4.0 are still growing concepts. Thus, there are still limitations which can be improved in the future. These limitations as well as the benefits of using this technology in Industry 4.0 are mentioned in the paper below.

Keywords - Digital Twin, Industry 4.0, Production, IIoT, CPPS, Manufacturing

I. INTRODUCTION

In last few years, markets have seen high rise in competitiveness given rise by increasing demand in change and flexibility by consumer preferences. The need to satisfy the consumer interests and improve the manufacturing process to keep up with these demands has prompted a new industrial revolution known as Industry 4.0 or fourth Industrial revolution. When compared to previous industrial revolutions, this one is developing at an exponential rate rather than linear, almost every industry has or is being affected in whole world. This industrial revolution is being driven by mainly digitalization of production process. One of the technological concepts which is the driving force behind aforementioned Industrial revolution is Digital twin (DT).

Digital twin is a very realistic virtual model of an object which behaves according to how itself world behave in real life according to its' properties and outside factors. Digital has the ability to link and process vast amount of information for fast simulations. This technology can be used for not only predicting product behavior but also for performing real time optimization of product and production process. Many reputable companies like Tesla, Siemens, etc. have already integrated DT technology in its production process. Siemens uses Digital twin in product lifecycle for three major sections of: product, production and performance. Other than manufacturing companies there are also other companies who has integrated DT technology for various purposes, like National Aeronautics and Space Administration (NASA). This company is also one of the pioneers of Digital twin. NASA used DT to develop ultra-high fidelity simulation models of Aerospace vehicles. These simulations have helped NASA' team of engineers to predict future performance and status of the vehicles. They have also used past and real time data to make informed decisions to improvise in-flight changes to vehicles mission.

II. LITERATURE REVIEW

2.1. Industry 4.0

The concept of Industry 4.0 comes from Germany. This concept came from the country which supports industrial development heavily, which in Germany, in form of a strategic initiative. This concept was first presented at Hannover, 2011.The main stimulants for bringing about fourth Industrial revolution were the development of Information and Communication Technologies (ICT). The aim behind the concept is to utilize all the potential of emerging technologies and concepts like– IoT, digitalization, smart factory and merging of technical processes and business processes in the companies to bring about Industrial development. It is estimated that Industry 4.0 could result in reduction of-

- production costs by 10-30%
- logistic costs by 10-30%
- quality management costs by 10-20%.

As the name suggests Industry 4.0 is the fourth industrial revolution. In the history the world has gone through three industrial revolutions, each having different characteristics. The fourth Industrial revolution is still ongoing. Different than previous three industrial revolutions, fourth industrial revolution is the only industrial revolution which we are aware of while it's still ongoing.

The first industrial revolution started in 1800's. It brought transition in manufacturing from manual labor work to mechanization of the processes. Improving the quality of life was the main impulse behind it.

The second industrial revolution was triggered by introducing electrification which brought forth mass production and industrialization.

The third industrial revolution was brought forth by help of digitalization and electric automation, examples being microelectronics and other automations. Use of programmable machines enabled more flexible production, resulting in being able to manufacture different variety of products. The third revolution brought efficiency in production by standardizing the products.

The fourth industrial revolution aims to introduce individualization of products while keeping the advantage of large-scale production. The main foundation for it based on IoT functionalities like smart automation of cyber-physical systems with decentralized control and advanced connectivity. Consequence of this will be to reform the archetypal automation systems to highly evolvable Cyber physical production systems (CPPS) which will enable to be flexible in production of mass custom products and production quantity. The Digital twin models will be used as base for Shortening time to market and to create further benefits along the entire lifecycle.

2.2. Digital Twin

The concept of the digital twin was birthed in the Institute of Automation, Measurement and Applied Informatics of the Faculty of Mechanical Engineering of the Slovak University of Technology in Bratislava. Digital Twin is a multi-physical, multi-scale, and probabilistic simulation model of a system. It uses various sensors, actuators, algorithms and physical models to mirror physical object in the digital world and vice versa.

The concept of digital twin was first mentioned more than a decade ago at the University of Michigan and was further developed by Michael Grieves in relevance with industrial presentation concerning PLM in 2002.The term digital twin has had different emphases at different times previously. It originated within the engineering class, it was in in relation to industrial products, where there was a clear link between the digital twin and the physical system at all stages of the product life cycle. Although this concept is still used today, over last few years, references to the digital twin of processes began to appear, where a clear link to physical and technological processes cannot always be traced.

What makes digital twin different from a digital model is that, it has automatic real-time transfer of data or information between virtual system and physical system as opposed to digital model in which data is to be manually uploaded. Sensors are built into the physical object which collect real-time data about the state of that object, the data is sent to a digital twin; a digital model is processed on the basis of the received data. The model takes into account all changes occurring to the physical object, accumulates information about its behavior and as it is more refined it is able to appropriately describe and predict the real-life behavior of object. Based on the updated model, recommendations for optimizing the operation and maintenance of the real object can be generated. For example, the model can predict the possibility of failure of a particular component, recommend timing of preventive maintenance, maintenance inspections, filter changes, etc. In digital twin the data flow is interlinked between both directions. As a result, the virtual model can simultaneously control the physical model, instead of just simulating it. And vice-versa, any change in physical model is shown by virtual model. Thus, change in state of one system may reflected in change of another system.

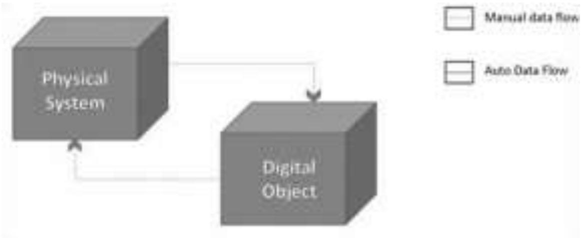

Fig.1. Digital model

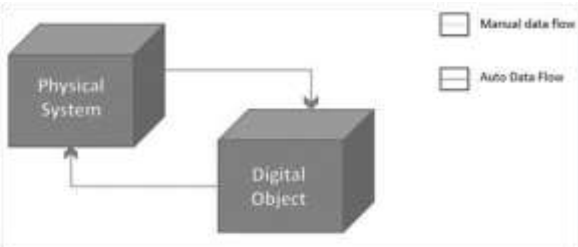

Fig.2. Digital Twin

2.3. Working of Digital Twin

The digital twin is an exact virtual representation of a physical object, which are achieved through the help of sensors. It is not necessary for the actual physical asset to be present for building digital twin, digital twin can be built even when physical asset is only in plans.

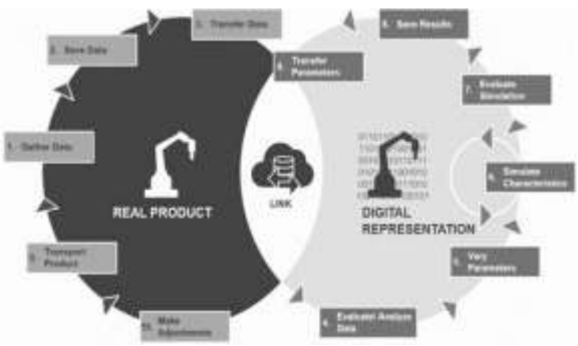

Fig.3. Working of digital twin, Dr.-Ing. Carsten Matysczok, Christoph Plass 2017, ADVANCING THROUGH DIGITAL TWINS, Smart Engineering.

For creating digital twin, collecting and synthesizing data of physical asset from all available sources is the first step for. The data procured is generally of type-physical data, manufacturing data, operational data and insights from analytics softwares. All of the collected data and AI based algorithms are unified into a virtual model with physics as a base, analyzing these models enables us to get real-life working insights of the physical object. The consistent flow of data enables us in getting the best possible analysis and insights regarding the asset which helps in optimizing the outcomes. Thus, a digital twin is formed which acts and behaves as a live model of physical asset.

The conceptual model of Digital twin is made up of five layers architecture of IoT platform. Which are-

1. Physical Space Layer
This layer includes technologies like physical objects, sensors, actuators, signal conditioning circuits, edge computing devices and power driving circuits.

2. Communication Network Layer
Main purpose of this layer is to transmit and receive the data gained from sensors, actuators and the edge-computing processing results, to the higher layers for further processing and analysis.

3. Virtual Space Layer
Virtual space layer is made up of two sublayers, namely data aggregation and data modelling. The data aggregation sublayer entails gathering sensor data of operational processes and environment received through the Communication Network layer, as well as physical assets past data, design specifications, and bill of materials since the data modelling sublayer and other upper layers will need to use it. Data modelling constructs a dynamic 3D model of physical asset being considered.

4. Data Analytics and Visualization Layer
DAVL accesses the data repositories to take the data and report results to management. This sublayer has two important tasks- (a) Complex Tasks that Include Data Cleaning and Processing And (b) Supervised machine learning through classification and regression techniques applied sensor data.

5. Application and Security Layers
The vast volume of data provided to the digital twin in virtual space is critical for the manufacturing process. This information aids in greatly increasing production efficiency, flexibility, and visibility.

III. ENABLING TECHNOLOGIES FOR INDUSTRY 4.0

The concept of Industry 4.0 was set in motion by development of information and communication technology also known as ICT, and introducing it to manufacturing industry.

The five major enabling technologies for Industry 4.0 are-

1. Industrial Internet of Things (IIoT)
Internet of things is a technology which binds many physical objects together making a network. This is done using various sensors, softwares and different technologies. In industrial IoT the information is gathered using different sensors, actuators and other similar devices which are used for industrial operations. This information is then stored in big data systems. It is then analyzed for further optimizing the manufacturing process.

2. Cyber-physical systems (CPS)
Cyber-physical system as the name says is a system which integrates physical system with network system. In Cyber-physical system the physical processes are monitored and guided by computer and the embedded networks using feedback loops.

3. Cloud Computing
Cloud computing makes it possible for companies to store, manage and analyze data on network managed storage like internet. The delivery services of IT sector based on resources are stored and retrieved from Internet rather than locally managed storage devices.

4. Big Data
The data collected from and for manufacturing processes are in huge quantity. To handle, process and analyze such data customized instruments have been made. This platform is called Big Data platform. While handling tens of terabytes of data, identifying patterns and trends becomes a dull and time-consuming task, tough the results of the analytics can give valuable insights that can support faster and better decisions for business. One of the examples of big data platforms is Amazon Web services, AWS big data platform.

5. Machine learning
Machine learning is a technology which makes it possible for machines to improve at tasks with experiences. Machine learning is type of AI, it uses algorithms to analyze and learn from the experiences and make intelligent decisions like humans, without further input from humans.
These five are the basic concepts which have given rise to many supporting and indispensable technologies like AR, VR, Digital Twin, Autonomous Robots, etc.

IV. DIGITAL TWIN IN INDUSTRY 4.0

4.1. Focused areas in manufacturing

The target areas of digital twin in manufacturing industry are as given below-

1. Production planning and Production control
In this process statistics-based inferences are used for making planning orders. Improves decisions are able to be made with the support of detailed diagnosis. This aids in the production units' automatic planning and execution of instructions.

2. Production Systems Maintenance
The first step in this procedure is to determine the influence of state changes on a production system's upstream and downstream processes. Here the

expected maintenance measures are identified and evaluated. In conjunction with it, Machine conditions based on descriptive approaches and machine learning algorithms are also examined.

3. Production Layout planning

Here a layout for continuous and simultaneous production system are planned and evaluated. The data gathering and variation is automatic and not dependent on application.

Implementation of Digital Twin technology has allowed us to operate virtual model in parallel with the physical system, giving alerts and generating valuable feedback to avoid any unwanted issues. This has made the production process cost and time effective, safe and more advanced. Some of the examples of digital twin for production purposes are-

- Motion Data in Production
- Cyber-physical Production System (CPPS)
- Factory and Production System Planning
- Simulation-based Production Optimization

V. DIGITAL TWIN IN CURRENT INDUSTRY

Digital twin is predicted to have rapid growth in upcoming years by analysts. The global digital twin market size in 2020 was estimated up to $5.04 billion by End-use (Automotive & Transport, Retail & Consumer Goods, Agriculture, Manufacturing, Energy & Utilities), By Region, And Segment Forecasts, 2021 2028, published in April 202, in their report on Digital Twin Market Size, Share & Trends Analysis. The market plummeted in first half of year 2020 due shutting down of many production and manufacturing industries due spread to Covid 19 pandemic. The digital twin market is estimated to rise up to $16 billion by 2023 according to Deloitte and a report by Techsci Research, published in February 2018. And according to Grand view research report the market is estimated to grow by 42.7% from 2021 to 2028.Companies have been using it for purposes like simulation of the manufacturing lines and products before the actual execution in the factory or using it is a business model by selling digital twin related solutions, etc.

Digital twin is being widely used in today's industry to increase production efficiency, planning efficiency and optimization. Digital twin is also being used for predictive maintenance dur its capability to predict future performance with the help of information collected from the physical systems, multi-physics simulations and data analysis. But this application is not widely adopted.

Companies	Application
Siemens & General Electric	Product lifecycle and Performance prediction
General Electric	Changing designing, manufacturing and maintaining their products processes
Tesla	Monitoring the operating condition of an electric vehicle, and detecting problems that may lead to expensive repairs in future
Boeing	Digitalizing whole system, which include supply chain information, data from the manufacturing system, and maintenance and support systems
Dutch start-up Connecterra	Remotely monitoring the health of cattle.
One Sydney Harbour	Identifying unresolved design details and errors.
Lendlease	Creating digital twins of buildings and other constructions
Cityzenith	Generating Digital twin of product lifecycle, from design to demolition.
European Union	To map climate change and extreme events as accurately as possible in space and time, a digital twin of the Earth is produced.
Medical field	Creating life digital twins of organs, 3D printing organ analogs, use of technology for improved planning and executing surgeries

Table 1: Companies and their applications of digital twin

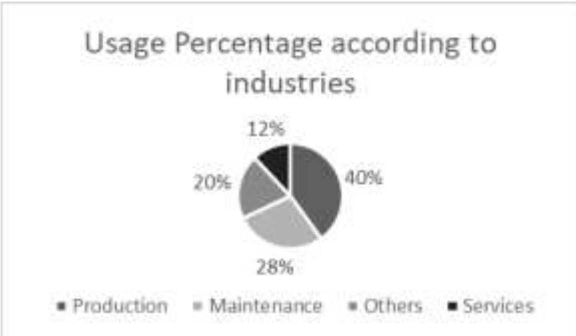

Table 2: Current trend of digital twin in various industries

VI. ADVANTAGES OF DIGITAL TWIN

1. Prediction

Virtual models developed by digital twin technology behave exactly like it would behave in reality. Due to this it is possible to make a digital twin even before object or system is made and use these digital twins as virtual prototypes. Not only for prototypes but it can also be used to find issues in existing objects or systems. This process is also used predictive maintenance.

2. Optimization

Digital twin has made the process of optimization very easy for the industry due to its capability to perform exactly as a physical object and also enabling to run many operations at a same time on said object.

The important thing in this process is the process of analyzing and optimizing which is done by computing machines. The only thing needed is problem statement and Additional data.

3. Visualization

It is possible to visualize the product according to real world conditions. Previously for visualization purposes prototypes used to be made, which were expensive and time consuming to make. But now it is possible to visualize a product before it is made with digital twin.

4. Advanced Testing

Digital twin provides us with methods of testing in a way never done before. The high-fidelity dynamic simulations enable us to test systems and models just like in real life. Some of these tests might not be feasible to be conducted in real life due to cost, size or environmental reasons.

5. Improves system integration

The systems in industry 4.0 are co-dependent on each other. Real-time monitoring using digital twin alongside cloud platform and big data analytics make it possible for increasing the interaction between systems.

6. Remote handling

Using of 4G and 5G network connected to systems, objects or production sites and their digital twin makes it possible for people to monitor and control these systems from anywhere even from homes. This has hastened the progress of fourth industrial revolution by realizing Cyber physical production systems in manufacturing industry.

VII. CHALLENGES FOR THE FUTURE

1. Expertise

The creation of digital twin requires expertise from multi-disciplines for determining mathematical modelling of complex physical, technological and production processes. Experts from IT sector are also needed for programming the software and enabling communication between devices possible.

2. High cost of projects

Requirement of highly qualified professionals, large quantities of information and lack of proper standards make creation of digital twin an expensive process. For future development quality handling processes can be improved and proper standards can be established for reducing high cost of projects.

3. Trust

The data handling for digital twin happens through IoT, cloud and AI platforms. There is a threat of data theft which reduces trust from this type of technology. There is also fear among populous due to use of AI and machine learning, that they will become autonomous become dominant on earth. Aside from that there is also problem of fraud among companies. There might be some companies which might promote themselves with a label of ‘Digital Twin’ despite using old technology. These types of companies may discredit digital twin and create mistrust about it. There is also a fear of being dependent on some other company or, sharing or losing confidential data.

4. Security

As discussed above the handling of data is done through cloud and AI platforms using high speed networks. While analyzing and storing data with such methods there is a risk of data being stolen. Currently there are no such rules and regulations against such thefts.

5. Data and IT infrastructure

Due to current technological limitations, it is there is problem for of data quality and handling process difficulties. For accurate results it should be ensured that only high quality of information is fed to the into the Algorithms. There may also be the problem of missing data. To run the AI processes highest quality and latest hardware and software should be used, which may be expensive to acquire or build.

VIII. CONCLUSION

In this paper a concept for use of digital twin for advancement of Industry 4.0 is achieved. A brief explanation of what is Industry 4.0 and digital twin is presented in this paper. We have seen why digital tool is an indispensable tool for development of various processes in industry. Digital twin has changed the face of manufacturing processes. It is an important technology for making production a cyber-physical process In the year 2021 there are many in industries which are using digital twin technology for increasing efficiency of their work. Many top companies of the world like Tesla and Amazon are also using this technology for various purposes like production, prediction, maintenance and remote operation. Digital twin despite having many benefits also has some limitations due to it being a relatively new technology. Every technology comes with its own shares of limitations. These limitations can be negated by further work and exploration in respective technology.

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