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Advanced Digital Twin Applications for Future Maintenance Optimization: A Review

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Abstract

This review paper covers research applied within the machine design and gears box. It will include multi-disciplinary work in information systems, system engineering, forecasting, modeling and simulation, maintenance, lifelong engineering, software engineering. The research site will extend the work to digital twins by building, compiling, analyzing, and disseminating algorithms for efficient and effective delivery of lifelong support solutions for sophisticated engineering products such as sliding mesh gearbox and synchromesh gearbox.Improvements in computer modeling, simulation, and communication between products and digital twins (DT) introduce new and different opportunities for value-added service and support through improved decision-making. The possibilities, risks, and requirements of digital twins are not fully understood in the literature, which makes this proposal subject to further research. DT's main challenge and essential benefit are reflected in the integration, integration, and analysis of data sources across the product life cycle, varying degrees from component to the system.Digital Twin (DT) can be used to predict how a body product will behave and function in the future in a range of other conditions and conditions. The primary research of this topic in developing algorithms will allow for the digital representation of tangible assets of many different contexts (e.g., working conditions, care interventions) within the care context. DT may be used to determine when and where any failure or damage may occur and repair it. Any unexpected failures or damage found will be added to the integrated DT so that the model always reflects the current state of the visible gearbox platform. TheIndian Gear Manufacturers Association (IGMA) focuses on developing knowledge, technology, and process managers to provide a conceptual design of high-quality engineering programs based on the design and production of lifelong engineering services. The IGMACenter hasunseen realities, digital twins, destructive tests, and artificial intelligence. The IGMACenter currently has several research contracts in work-related areas and offers an excellent reputation at national and international levels. The main focus of this study is to improve the role of DT utilization at the level of repair, repair, repair, and rehabilitation (MROU) equipment. This will aim to define what maintenance interventions need to be implemented initially to meet MROU's vision of improving living and working costs. This study develops digital twin algorithms that integrate computer representation with fast visual stimulation within the correction environment.

Keywords: Applied research, Digital twins, Software engineering, Modeling, Gearbox, retention, lifelong engineering.

Introduction

Digital Twin Technology can be described as ai technique that uses data connections for engaging or l inking a physical entity co a virtual entity, this technology is being continuously explored to Drove the overall performance of their product by I implementing computational technology & such as the use of IOT, Data acquisition, cloud computing, etc. to meet the volatile customers demand[l]. Interest in Digital Twin has grown n significantly over the past five years in both academics and industry, accompanied by growth in several related publications, processes, concepts, and perceived benefits [2].

overall Decades industry is utilizing and different kind of modeling and simulation technique to reduce the development time and overall cost of a product or system while keeping the quality unharmed or moreover to improvising it [3]. Bu t challenges occur due to constrained in tile modeling tools because of their domain-specific nature which intends to lead to an increase in the overall complexity of the designing process. With these constraints, it is also impossible to verify the design work in real-time virtually [4].

Digital twin technology plays an important role co resolve the challenges that occurring modeling and simulation techniques by enabling a virtual product of design that can

analyse and evaluate a large amount of data in the simulation to optimize the design data for real -time planning. Digital twin technique can also be used in various propose at application for real -time data acquisition at field level to choose between a type of action plan for running ng a system in an optimized way which will result in higher system efficiency and accuracy to gain more and more economical benefit for the industry [5]

This paper discusses the Digital Twin Technology concept in maintenance science based on systematic literature research. This review article aims to enlighten the concept of immensely growing technology for its implementation in the maintenance field.

This paper is structured as follows within section 2 what is digital Twin Technology and its importance in maintenance,

Use of Al and IOT in technology, in section 3.

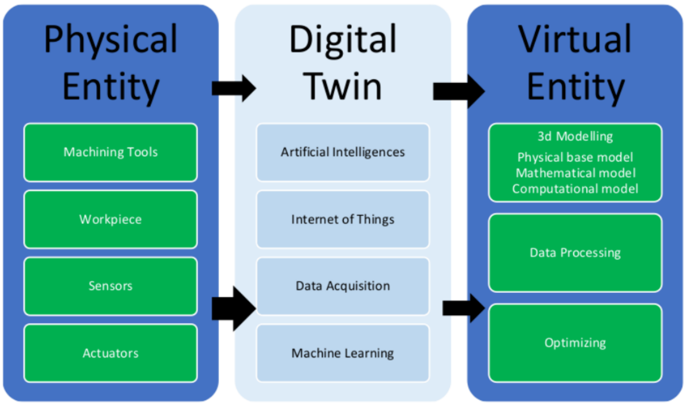
Limitations of Digital twin, in section 4.

The review article is then concluded, in section 5

Digital twin technology and its importance in maintenance

Digital Twin technology was firstly introduced by Michael Grieves at theUniversity of Michigan in a presentation on Product Life-cycle Management (PLM) in the year 2002 [6]. As of now, it has become superior technology in industry 4.0 due to its immense capability in optimizing a process with real-time solutions. Taking this context as a major advantage many pioneer companies such as Ansys, Dassault Systems, IBM, PTC, Bosch, Jaguar, etc. in their Business by their means and modified as per their need [6]. But the base of this technology is being taken counting entities viz.

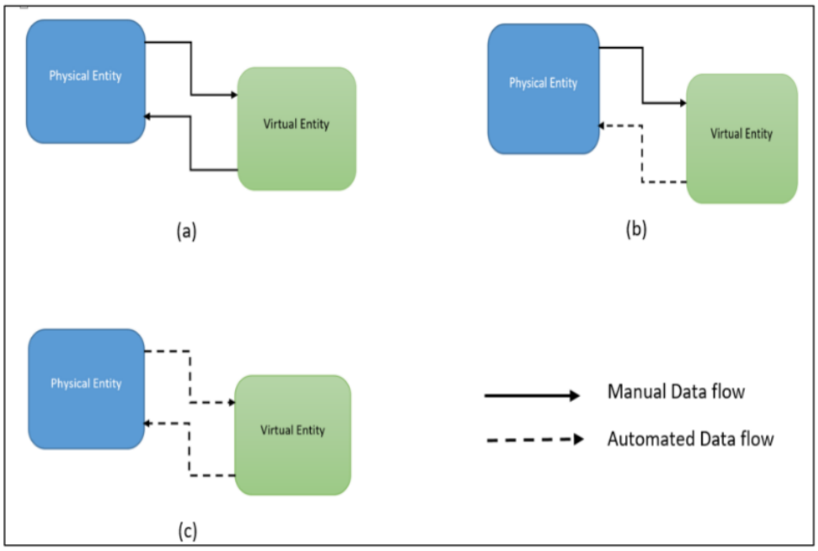
1. **Physical Entity**.
2. **Virtual Entity** and **Digital Twin** is the link between the first two entities.



a) b) c)

Figure 1 Defining Entities and Digital Twin

Physical Entity is the actual physical object (cited in figure 1 (a)) that has to perform the given operation on a workpiece. This Physical entity is rarely in an automated connection with any data sensing or uses any data acquisition technique for optimize ng the operation process, Data sensing down on this Physical entity or object is usually done manually (As represented in figure 2(a)). After the manual data acquisition ls done a person analysis this data to optimize the operation process and make changes as per the requirement in the process. These changes are also performed manually [7] [8].



Virtual Entity is the virtual representation of the physical entity in a modeling tool as cited in figure 1(c) that is in connection with data sensi ng and data acquisition technique in an automated manner represent. I in figure 2(b)). Th is automated data sensing and acquisition technique then analysis the data to produce a solution that can optimize the operation process. However, virtuality is only capable of providing a solution for optimization of a process but.it is unable to make any kind of changes or improvisation in the physical entity. The solution given by the virtu al entity is then performed by a person manually represented in figure 2 (b)) to optimize the operation process. While doing so There is a high chance that the process may not be able to optimize fully as per the solution given by the virtual entity. This. may be idle to mistakes or changes done by the person while executing the solution provided by the virtual entity or there is might be because the solution is not given in real-time [7][8].

Digital Twin links the physical and virtu al entity with each other where the virtual entity will sense the data by using multiple IOT sensors and analysis the sensed data by using multiple dataacquisitiontechniques,cloudcomputing, modelingbasedesigntechnique, etc., (cited in figure I (b)), Which will provide a real -time solution to optimize the operational process 19]. Digital Twin is also able to implement the changes as per the solution taken om by technique on the physical entity in an automated way without interference from any person [IOT Bits will ensure the implementation of the solution is working with 100 l"o efficiency for optimization of the operation process. The digital twin is also capable to alter the changes implemented to the operational process for optimizing it further as per need of the hour due to its capability to provide a real-time solution [11]

Use of IOT and AI in Digital Twin Technology

IOT/IIOT

IoT can be described as the network which enables the data exchange between Microsoft software, and other technologies with other devices over the internet [12]. As in industry 4.0 IOT viz. IIOT (Industrial Internet of Things) has become an importanttechnology due to its seamless communication is passible between human s and. machines. Enabling IOT in the production line can positive the maintenance a greater advantage to reduce the overall operating costs, get better on-time production by monitoring the production line to enable productive maintenance of tools and equipment [13]1. When a sensor will detect. a failure IoT can alert the maintenance about thefailure. The maintenance then can take measures to overcome the failure by inspecting the particular equipment for its accuracy or either replacing the required equipment [14]

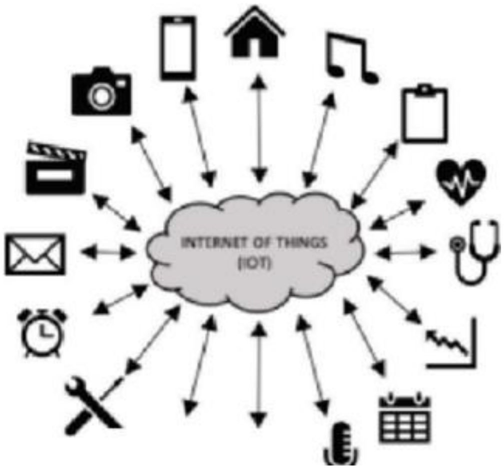


Figure 3. Internet of Things diagram [14]

Artificial intelligence

Digital Twin Technology takes this use of IIOT one step higher and combines IIOT with AI (Artificial Intelligence) [15]. AI is another industry 4 .0 technology that is capable to overcome some issues regarding maintenance on its own by u sing some pre-saved data in it. With Al the machine can complete an assigned task from given data in an intelligent manner. Al can give an output of an optimized product in a shorter amount of period as compared. to the human brain [16]. Due to this advantage of producing an optimized product over a shorter peri od industry has implemented this technology in their way [17].

Digital Twin combines these attributes of IIOT and AI with each other in sculpt a manner that the IoT collects the data from the sensors. and provides it to AI which analysesthe data and make decisions and act on that data without involvement by humans. This combination results in in to overall enhancement in the machining process and reduction in operation time.

Categorical Review of Digital twin in Maintenance

A. Bilberg and A. Malik[18] offer an event-driven Digital Twin that works in conjunction with robotics to see how they may be adapted for a maintenance process. On an assembly line, work in tandem robot lo complete jobs. The other links the physical and virtual tasks into one. o builds a real-time, skill-based robotic assembly line allocating work to a person or a robot based on the accuracy of the maximum amount of output they could each achieve[l8].

S. R. Chhetri, S. aezi, A. Canedo, and M. A. A. Faruque [9] cite that the surge in smartmanufach1ring design and developments can be attributed advances in digitalization. The authors offer a technique and conduct a ca study to create a Digital Twin of a maintenance process that advantage of IoT expansion. IoT sensors are utilized in this methodology to gather and store data streams that are used to highlight side-channel states such as acoustics, power, and magnetic output of a process. These can be used to pinpointproblem and pinpoint maintenance process issues. The team backs up their findings with a case study of a Fused-Deposition Modelling system (FDM), the first of it's in this format, which achieves high-accuracy anomaly detection [19].

D. Shangguan ,L.Chen, and J. Ding[20] present a method that incorporates the utilization of Digital Twins while also introducing the Physical System (CPS) trend. Jn a smart maintenance setting, the authors describe a Hierarchy Digital Twin Framework HDTM for the design and development of dynamic CPSs. The Digital Twin is used at all stages of the CPS design process, allowing for the reuse and testing of physical data on a virtual twin. The authors conduct a case study to demonstrate the advantages of Digital Twin, which are best demonstrated here since it allows the authors to employ the twin in a real-time predictive design scenario as well as learning for large-scale system adjustments.A framework is a tool for designing e: industrial robots.[20].

Both Lu et al. [30] and Mawson [21] provide energy-efficient maintenance techniques and architecture. The environmental advantages are a driving force behind this. More efficient production, on the other hand, will save costs, improve profits, and allow for future expenditures. Luteal. offer a work that focuses on designing architecture that leverages a platform called M Cloud w construct: an energy-sensitive Digital Twin model. Both of these technologies help to create an Industry 4 .0 environment in which production processes are continually monitored and self-configured using CPSs and DigitalTwins, with energy efficiency as the main aim.

V .J. Mawson and B. R. Hughes[21] also on industry 4.0 advancements, noting an evaluation of their usefulness for enhance durum on , connectivi1.y , and flexibility i n industry processes. The paper 's main contributions are a comprehensive review and case study based on methodologies and frameworks derived from energy consumption analysis at the machine process level. Various simulation tools are mentioned l by Mawson el al., but none of them have multi-level integration. To build a high-accuracy, all components of the maintenance process must be included, from materials to resource flows, precisely analyse energy use. These are issues that demonstrate how Digital Twins, Virtual Reality, and Aug minted Real time

Q.Mi n, Y .Lu , z_ Liu , C. Su , and B. Wang[22] present a paper that comprehensively! he key enabling technologies, with a focus on digi1al twin solutions that use Al,will aid future specifically, machine learning, and provides thorough evaluations. The paper employs a case study to assess the benefits and drawbacks of employing machine learning and Digital Twi ns i11 the petrochemical industry, with each being applied to an industrial IOT pyrochemical factory. The Digital win and algorithms are unique to a petrochemical facility, which was discovered as a constraint during the case study. Transfer learning could be used to uncover commonalities in algorithms, allowing for the creation of collisions that could be applied to various industrial process. [22]

Y. Xu , Y. Sun, X. Liu , and Y.Zheng [23] present a simulation study that discusses a Digital
Twin approach to fault diagnosis for distributed photovoltaic systems (PV). The advancements in Digital Twin technology allow the team to develop a Digital Twin that can estimate accurately faults relating to PY energy un it's in real-time[23]

D. Howard [24] Presents as per that examines the Digital Twin trend, analyzing its applications and applicability for the ever-evolving smart maintenance environment. The main goa l achieved was the design and development of maintenance electronic hard ware using a Digital Twin for "virtual validation."

P.Jain, J. Poon, J. P. Singh, C. anos, S. Sanders, and S. K. Panda [15]provide an AI- based defect diagnosis solution in a smart maintenance setting . Xu et al. point out that establishing correct AC algorithms for new maintenance processes requires a large quantity of training data, which is also required to create accurate Digital Twins. To ensure that any issues are addressed, the model's front end is powered by a Digital Twin that learns and identifies flaws while creating training data. Using the obtained training data from phase one of the method, the second phase can then employ transfer learning. With the u se of a Digital Twin and transfer learning, a more accurate defect diagnosing method can be developed. The authors give a practical case study in which the concept is tested and evaluated i n a car production context 25].

W . K uehn] explains a concept in which "virtual clones" of a system are used in conjunction with machine learning algorithms to improve the maintenance process. The author categorizes key areas. in a maintenance process to highlight their specific goals and concepts for applying a Digital Twin to the maintenance process, allowing businesses to test, simulate, and optimize maintenance processes in a virtual environment, resulting [4]

Q.Qi and Tao[27] provide a "360" of Digital Twins in the context of big data inmaintenance and industry . It compares Digital Twin enabling technologies and argues for the importance of emerging technologies in the development of smart maintenance [11]

K. Sivalingam, M. Sepulved a, M. Spring, and P. Davies Review [28] and create a case study for a smart grid that looks at the use of wind farms and energy consumption. The study discusses some of the issues surrounding power consumption dependability and wind turbine maintenance in general. The authors <Ger a workable technique for performing and predicting wind turbine maintenance u sing IOT sensors paired with data analytics in a Digital Twin environment [28][30] and [23]] are two review articles present y Tao; the first [30] examines Digital Twinsand Cyber-Physic system in context fi smart maintenance. The latter, by Tao [30], is a cutting-

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edge paper for Digital Twins and industry. Both papers discuss enablingtechnologies such as IOT, cloud, big a and artificial intelligence, as well as how DigitalTwins are used in these technologies. Digital Twin simulation, Digital Twin "as a service," data fusion, and interaction and cooperation a some of the key application purposes mentioned by Tao [32]. Both point to the rising development of industry 4.0 technology, with a focus on data analytics and artificial intelligence

Challenges in implementation of Digital Twin in Maintenance.

Regardless of the benefits., Digital Twin technology also comes with some challenges. The challenges come ahead of engineers while enabling Data Analytics, IOT/IIOT in digit al twin technology.

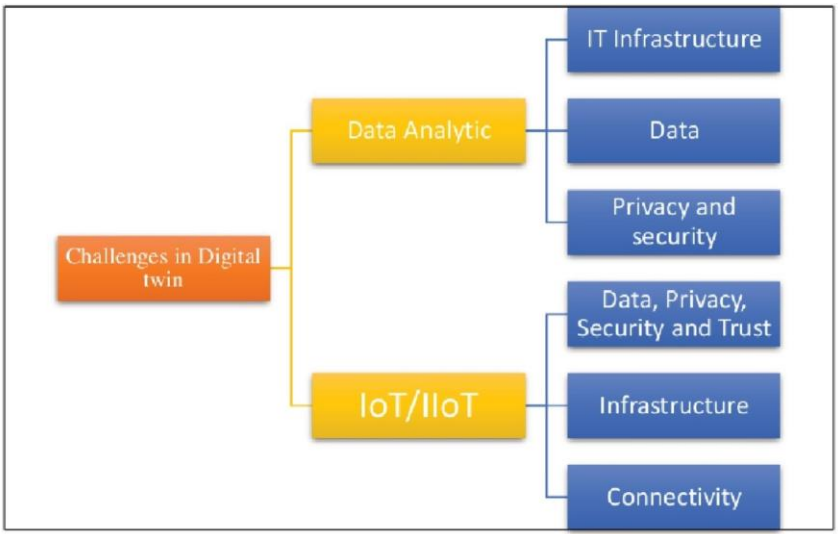

Figure. 4 Challenges in Implementation of Digital Twin in Maintenance

Data Analytic Challenges

1) IT infrastructure

The initial Installation cost of high-performance IT infrastructure which needs to be compatible to execute the algorithm processed by artificial intelligence is the first IOT challenge. Also, there is a need to keep IT infrastructure up to date both ln hardware and software format to get the best outcome. Some companies such as Amazon, Google, Microsoft, and NVIDIA provide an on-demand GPS service over some cloud applications. Using this on-demand service might reduce initial installation cost but the concern of security is still in count.

2) Data

The second challenge comes of data and data collected by the IOT /IIOT sensors need to be sorted in such a manner that only the highest quality and needed data is fed into artificial intelligence ensuring the AI performance well to provide efficient algorithm tooptimize the Maintenance process

3)Privacy and security

Privacy and security of data is another big challenge as the data flow is performed through IOT or cloud applications Maintenance are required to ensure the security of their server for preventing any server breach which leads to both financial and technological losses of the company.

IOT/IIOT challenges

1) Data, Privacy, Security, and Trust

The industry has seen the benefits of IOT de Ss over time, taking this into count setting up multiple IoT dev ices can be efficient for the implementation of the digital twin. Collecting this huge amount of data is challenging. As the volume of data increases it is essential to control the data flow between entities in an organized. Otherwise, it will become difficult and time consuming for Al to process and give the best algorithm to optimize the process

The use of multiple IOT in organizations also challenges maintaining privacy and security of the data flow. The volume of data is huge, and ii is essential to keep an eye on the data flow for breaches through the internet as the data may cost the organization in many terms financially and technologically. Trusting the IOT devices is another challenge as the use of third-party devices might threaten [n leaking out the data

2) Infrastructure

Initial infrastructure co use multiple IOT devices is a challenge to get the best IOT device which will meet the need of the organization since there are many IOT device manufacturers and to get the best out of it is a difficult task while keeping data security, privacy, and trust in the count.

3) Connectivity

Connecting multiple IOT devices is another challenge. It is essential to provide controlled, accurate, sorted, and u uninterrupted data flow between entities. Data flow must be real-time to execute the best algorithm for -optimizing the process. Just a slight mistake in the connectivity between entities may cost the AI algorithm badly.

Conclusion

As given by others searchers, Digital Twin Technology is. widely being used in multiple disciples hence, there is no common define about Digital Twin Technology. For the further development of the technology, it is necessary to define a common definition of the technology. As well as the domain-specific model w i11 also be helpful to develop technology in a focused area a common definition is proposed in this review based on the literature review. The literature review shows that the Technology is still in its developing phase and mainly consists of a research paper without a solid case study. II also shows that the technology has a huge potential in providing a solid base to make the production of a product more efficient in terms of operation cost as well as further development of the product as per the need of the market. As of now, the research is mainly focused on planning and control of maintenance as it is the main aspect of the to avoid failure and other things revolve around it. But as seen in the literature review Digital Twin has mover potential than just contributing to planning and control of Maintenance. This shows the further research needed with being the specific domain of optimization to showcase the possible benefit of the Digital Twin in Maintenance.

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