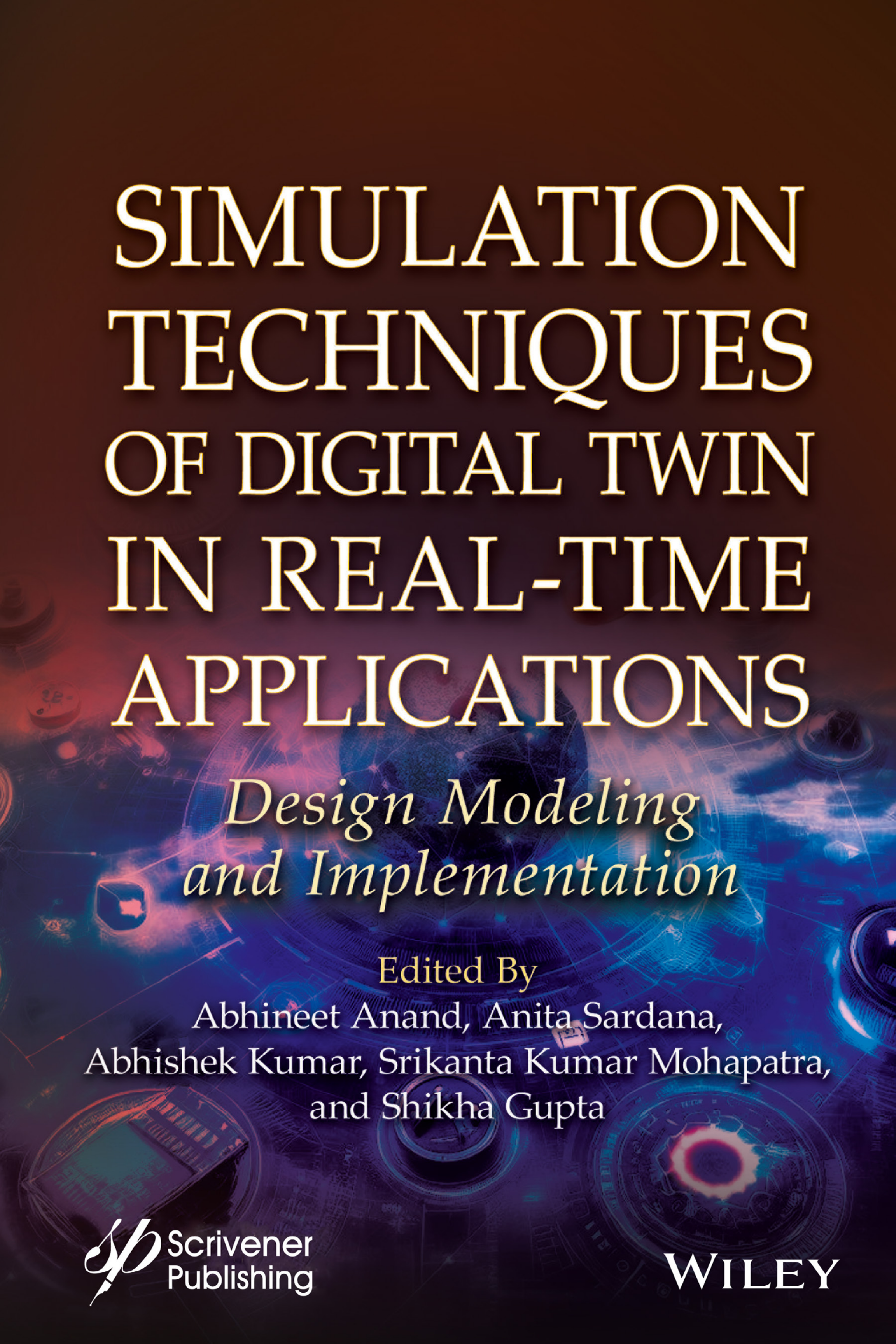

SIMULATION TECHNIQUES OF DIGITAL TWIN IN REAL-TIME APPLICATIONS

Design Modeling and Implementation

Edited By
Abhineet Anand, Anita Sardana,
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Scrivener Publishing

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Simulation Techniques of Digital Twin in Real-Time Applications

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Beverly, MA 01915-6106

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Scrivener
Publishing

WILEY

This edition first published 2024 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA
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Library of Congress Cataloging-in-Publication Data

ISBN 978-1-394-25697-6

Cover image: Pixabay.Com
Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Dedication

For our gurus, parents, and God, we dedicate our book. Their blessings are the reason for our motivation.

Contents

Preface

Currently, a great amount of research is invested in the development of models and exploring their implementation. Digital twin technology is just the replica of an object in digital form. Generally, this technology improves the capability to receive real-time data and produce the data pool of the original object. This book is for researchers of diversified technologies, and the main objective is to showcase the proposed research models to a real-world audience.

This book collects a significant number of important research articles from domain-specific experts to present their works to the readers. A useful platform for both researchers and readers, this book gives a better understanding of how Digital twin technology may be the next big thing in the context of sustainable sectors to industrial sectors. This book sheds light on the various techniques of digital twin that are implemented in various application areas. It emphasizes error findings and respective solutions before the actual thing happens. Most of the aspects in this book are the implementation of strategies in real-time applications. Various real-life experiences are taken to show the proper implementation of simulation technologies. Overall, the book is for the readers to manage real-time applications or problems with the help of replicated models or digital twin technologies.

The book shows how authors of any technology can input their research ideas to convert to real scenarios by using replicas. Hence, the book has a collection of research articles from various authors with expertise in different technologies from many regions of the world. It will give an idea to implement the real-time data embedded into technologies.

Specifically, the chapters herein relate to the auto landing and cruising features in aerial vehicles, automated coal mining simulation strategy, the enhancement of workshop equipment, and implementation in power energy management for urban railways. This book also describes the coherent mechanism of digital twin technologies with deep neural networks and artificial intelligence.

Overall, the book gives a complete idea about the implementation of digital twin technology in real-time scenario. Furthermore, it emphasizes how this technology can be embedded with running technologies to solve all other issues.

This book comprises two parts: Part 1—"A Guide to Simulated Techniques in Digital Twin" and Part 2—"Real-Time Applications of Digital Twin". In Part 1, Chapter 1 introduces digital twin modeling. Furthermore, it specifies that engineers and designers employ simulation, a key step in the development of digital twins, to generate and test various scenarios in a secure and controlled environment. Many simulation techniques are widely used in the development of digital twins, including FEA, CFD, DES, MBD, MCS, and ABM. There are pros and cons to each of these techniques, but they may all be used to imitate and enhance particular aspects of the physical system. As digital twin technology advances, new simulation techniques and tools will emerge, allowing engineers to create more accurate and comprehensive models.

Chapter 2 shines light on the future of today's manufacturing lines. Furthermore, it clarifies that twin model is clearly headed toward advanced real-time simulation frameworks taking the lead. These frameworks, built on the digital twin principles, have ushered in a new era where real-time data synthesis and prompt feedback are not just useful but essential. Production simulations are now more realistic, precise, and comprehensive thanks to digital twin. The growing use of digital twin of traditionally physical systems has enabled industries to predict issues, make precise predictions, and base decisions on real-time data.

Chapter 3 discusses an air purifier system. The air quality, energy use, and cost-effectiveness of the air purifier system are all predicted by the LabVIEW simulation model. The digital twin concept can improve the efficiency, effectiveness, and cost-effectiveness of air purifier systems. The most effective and affordable air purifier system layouts can be found through analysis using the digital twin approach. The digital twin model might simulate how pollutants impact air quality and air treatment technologies. Research may enhance air quality, energy effectiveness, cost effectiveness, and air purification innovation.

Chapter 4 generated results that indicate that the suggested model did well on the classification dataset. It has very good accuracy, precision, recall, specificity, and F1-scores (between 96.85 and 99.3). The findings demonstrate that the model can accurately distinguish between those who genuinely have the illness and those who do not. The healthy class showed positive results, indicating that the model successfully distinguishes between healthy (normal) and damaged leaves.

Chapter 5 discusses various signaling methods, including BDPSK, BPSK, BFSK, QPSK, NCFSK, MPSK, MQAM, DQPSK, MDPSK, and NCMFSK over F fading channel, which have had error rate equations calculated for them in this study. The asymptotic, tightly bound, and approximate expressions of ABER have now been calculated. Additionally, the many expressions of capacities have been discovered. For the purposes of generalization and validation, a few reduction examples are also described. The analytical results have been acquired, and simulation results support them.

Chapter 6 looks at the effectiveness of the F model when combined with MGF. The expression for MGF is first derived. We have determined the expression for BER utilizing a variety of signaling schemes, including BDPSK, NBFSK, BPSK, BFSK, MSK, MAM, Square MQAM, MPSK, and NMFSK, using the suggested MGF. Additionally, the ORA and CIFR capacity expressions are computed. Through the use of Monte Carlo simulations and special case outcomes, the accuracy of the result has been verified. According to the study, higher-fading severity parameters perform better in terms of BER and channel capacity than lower ones.

To begin Part 2, Chapter 7 works on the creation of virtual replicas of real cars which is made possible by the use of digital twin technology, enabling prolonged testing in a controlled environment. By modeling numerous scenarios and driving conditions, developers can evaluate the performance and capabilities of autonomous driving systems without the need for real-world testing. This avoids wasting time and money and guarantees that the technology is thoroughly tested before being used on public roads.

Chapter 8 summarizes the study's major conclusions and learnings in digital twin modeling. Real-time information, including voltage, current, and temperature, are gathered by sensors for transformer condition monitoring. Therefore, this information is sent to the computer. The use of a MATLAB-based ANN-based intelligent monitoring system that is connected with the hardware to produce digital twins demonstrates tremendous potential for enhancing the precision and effectiveness of power transformer failure analysis through temperature monitoring.

Chapter 9 gives a thorough explanation of the integrated deep learning digital twin approach. For the purpose of advancing digital twin technology, authors have examined several forms of digital twins and the ways that deep learning techniques are applied in various simulation models. They have researched a variety of current publications that use deep learning to enhance the functionality of digital twin models.

Chapter 10 discloses an online system identification or virtual modeling approach. There is huge potential for the use of digital twin (DT) in dynamical systems, including active control, health monitoring, diagnostics, prognosis, and computation of remaining useful life. However, the implementation of this technology in real time has lagged behind schedule, largely because there is a dearth of data pertinent to the application being used.

Chapter 11 describes UAVs that use digital twin-based techniques, which have a great chance of performing autonomous takeoff, landing, and cruising. The findings of this study add to the body of knowledge already available on UAV autonomy and highlight the need for more research in this field. Overcoming the challenges and researching the suggested future courses are necessary to fully realize the promise of digital twin-based autonomous operations and drastically transform how they are used in many businesses and sectors.

Chapter 12 explains digital twins and artificial intelligence (AI)-powered algorithms to increase productivity, safety, and sustainability in the mining industry, as the adoption of such a system alters coal mining operations. Overall, the DT is making headway, and thanks to its almost endless potential, it is becoming a more significant and well-liked competitor in the race. The authors are one step closer to making actual DTs with the development of its underlying technologies, which are constantly evolving.

Chapter 13 analyzes real-time data from the aircraft's sensors and systems. Digital twins can foresee likely defects or maintenance needs. This proactive approach helps to reduce unscheduled downtime, enhance maintenance schedules, and improve aircraft availability and reliability. By combining digital twin technology with artificial intelligence and machine learning methods, the prediction abilities of Digital Twins will be enhanced.

Chapter 14 relates to energy consumption, which is closely related to power consumption in urban trains. The system's energy performance demonstrates that energy in both reference instances is gradually rising. An error result of less than 1% is also displayed to demonstrate accuracy. Therefore, the aspect of concern is power consumption or energy utilization. The involved railroad authorities may find these results helpful in describing the user-label experience. These results also demonstrate that the simulation can use certain preventative measures.

Chapter 15 describes pipedream, which is a cutting-edge system that enables real-time hydraulic state forecasting and interpolation for urban fast-flood nowcasting. The pipedream toolset's data assimilation method can be utilized by emergency management to estimate localized floods at ungauged locations, enabling rapid flood response and targeted emergency service dispatch.

We would like to express our gratitude to the writers and contributors for their efforts as well as to Wiley and Scrivener Publishing for their cooperation and assistance in the timely publication of this book.

The Editors
March 2024

Part 1

A GUIDE TO SIMULATED TECHNIQUES IN DIGITAL TWIN

1

Introduction to Different Simulation Techniques of Digital Twin Development

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Abstract

Virtual models of actual systems, processes, or products are known as "digital twins" in technology. It replicates an object or system's behavior, functionality, and responsiveness to various circumstances using a software version of the real-world counterpart. In addition to manufacturing, healthcare, construction, aerospace, and transportation, there are numerous additional sectors that use the technology. With the use of digital twins, businesses may increase productivity, decrease downtime, maximize resource use, and enhance decision-making. The following simulation methodologies can be applied in digital twin technology: computational fluid dynamics (CFD), finite element analysis (FEA), agent-based modeling (ABM), multi-body dynamics (MBD), discrete event simulation (DES), and monte Carlo simulation. The foundations of digital twin technology are covered in this chapter, along with the benefits they offer to real-world research applications. This chapter also discusses several simulation methods for the practical uses, advantages, and disadvantages that will be covered in later chapters.

***Keywords*:** Digital-twin technology, agent-based modeling (ABM), finite element analysis (FEA), discrete event simulation (DES), computational fluid dynamics (CFD), Monte Carlo simulation, multi-body dynamics (MBD)

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Abhineet Anand, Anita Sardana, Abhishek Kumar, Srikanta Kumar Mohapatra and Shikha Gupta (eds.) Simulation Techniques of Digital Twin in Real-Time Applications: Design Modeling and Implementation, (3–24) © 2024 Scrivener Publishing LLC

1.1 Introduction

Digital twins are frequently described as "a digital representation of a real world object with focus on the object itself" [13]. Figure 1.1 illustrates the extensive application areas of digital twin technology across various industries [1]. This visualization showcases the diverse utilization of digital twins in sectors such as manufacturing, healthcare, and urban planning, highlighting their significance in enhancing operational efficiency and facilitating predictive analysis.

A. Digital twin features
Technologies for creating, managing, and analyzing digital twins—virtual representations of actual systems or processes—are known as "digital twin technologies." Among the crucial elements of digital twin technologies are the following:

Data integration: Digital twin technologies combine information from several sources, such as IoT devices, sensors, and other systems, to create a full image of the physical system or process.

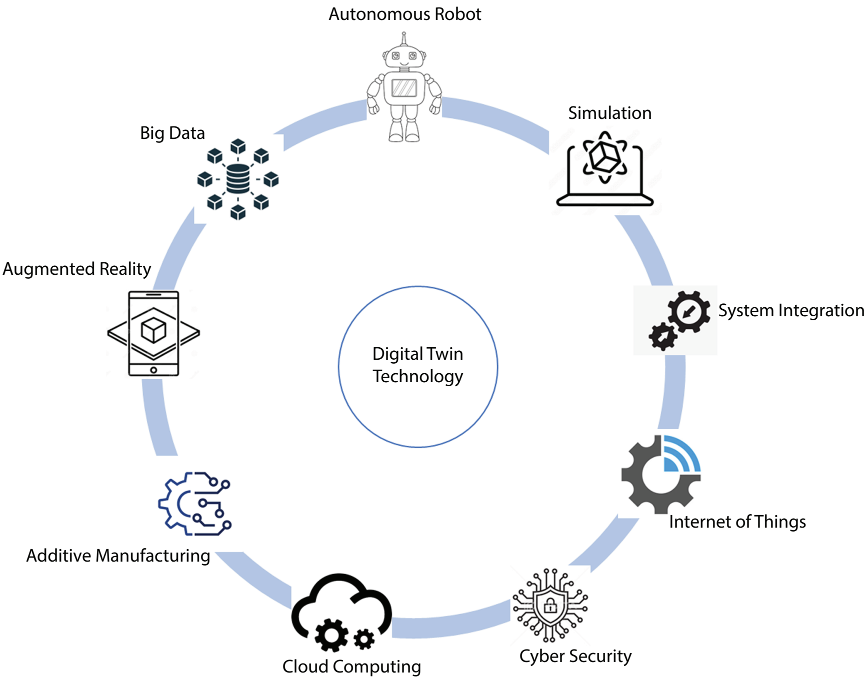

Figure 1.1 Different application areas of digital twin.

Simulated and modeled learning: In order to build virtual representations of actual systems or processes, digital twin technologies employ simulation and modeling approaches. With the help of these models, the behavior of the physical system under various conditions may be forecasted and studied.

Real-time monitoring: Digital twin technologies offer real-time observation of the physical system or process using data from sensors and other gears. Engineers and operators can now quickly identify and deal with any new issues as they arise.

Prevention-based maintenance: Based on information gathered from sensors and other devices, digital twin technology may be used to forecast when maintenance is necessary for the physical system or process. By doing so, downtime may be cut down and overall productivity can rise.

Optimization: The functionality of a physical system or process could be improved using technologies like digital twins through data analysis and the identification of issue areas. Increased effectiveness and lower costs may result from this.

Collaboration: Communication between numerous teams and departments is made feasible by digital twin technologies' shared image of the physical system or process. This can improve dialogue and facilitate problem-solving.

Machine learning and artificial intelligence: By analyzing data and making predictions about how a physical system or process will behave, digital twin technologies may make use of machine learning and artificial intelligence algorithms. Making decisions will be more accurate and effective as a result.

The ability to create and maintain virtual representations of actual systems or activities is provided through a number of capabilities provided by digital twin technologies, which are used by engineers and operators. These characteristics can help with cost reductions, performance improvements, and efficiency increases.

B. Digital twin classification

Digital twin instance (DTI): A certain type of digital twin is referred to as a "digital twin instance" when it continuously depicts its physical counterpart across time in line with its specification [14]. As a result, the physical twin is continuously monitored, and any adjustments or changes it goes through will affect the digital twin. In this perception, the aim keeps track of and predicts the behavior of a process or product from the moment of its conception until the end of its existence. Validating a product's or object's predicted performance and behavior is helpful.

Digital twin prototype (DTP): A digital twin prototype gathers and stores important information and features about a product's physical counterpart when it comes to the design and production of that product. Diagrams, computer-aided designs (CADs), and even information connecting persons involved in the production chain with the manufacturing process are examples of data [14]. Before the actual manufacturing process begins, the DTP may simulate production situations and carry out validation testing, assessments, and even quality control testing in accordance with DT requirements. By detecting defects or potential dangers in the physical twin before manufacturing, this method efficiently minimizes production costs and operating time. DTPs are also sometimes referred to as experimentable DTs in this sense, where, in accordance with [15], it is possible to access a virtual prototype whose degree of detail grows over time, and virtual test results offer an adequate evaluation of the design's quality while reducing the need for normally affluent hardware architypes.

Performance digital twin (PDT): More realistic and unforeseen situations can be monitored, collected, and evaluated by the PDT than they can by physical twins [14]. The PDT can analyze the data being tracked from the physical equivalent by fusing its smart capabilities. The processing yields useful information that may be applied to design optimization, the creation of maintenance plans, and the drawing of inferences from a product's capability [16].

1.2 Literature Review

A. Digital twin technology: Based on the fact that DT technology is still in its infancy, it will be crucial to overcome the many obstacles that a contemporary DT deployment faces, such as costs, information complexity and maintenance, a lack of standards and legislation, issues with cybersecurity and communications, and issues with standards and regulations. When assessing DTs in the three areas of technology, social readiness, and maturity, the maturity spectrum examination of major publications, as well as the TRL, SRL, and maturity analysis, are all very beneficial. The evolution of DT technology and maturity has only just started for the vast majority of applications. Although advanced DT uses are addressed in [1], more work has to be done before DTs may be fully enabled, accepted, and sustained in practical settings. The development of DTs will be aided by technologies and techniques for data processing and analysis. To address the issues brought up in this paper, future research should concentrate on the following areas: 1) computing complexity reduction through simulation and modeling, 2) 5G communication, 3) data from the Internet of Things can be processed and analyzed using big data, machine learning, and artificial intelligence, 4) the capacity of simulation, modeling, analysis, and visualization software to cooperate and integrate, and 5) recent technical advances including, but not limited to, the inclusion of edge and cloud computing potentialities in current microprocessors. One will be able to make a more accurate assessment of the current state of the art and the direction that technology is moving if they are aware of the whole picture of DTs across many crucial fields. It is crucial to take on the suggested research projects if DTs are to completely deliver on their promise for the future.

In [2], the conclusions are as follows:

(1) A variety of naval equipment can be built using the full digital twin (DT) architecture, and the DT approach demonstrated for the horizontal axis tidal turbine (HATT) performs well in simulations and tank tests. Instructions for the DT model may be broadcast to the outside world in order to achieve self-learning, and data can be utilized to translate changes in the physical environment to the digital environment.

(2) After several mechanical learning sessions, the substantial error in the DT data that the interpolation approach produced was decreased to less than 10%, which is regarded as being within an acceptable range and can be used as engineering reference values. The monitoring and performance assessment process for any marine equipment might be covered by this system.

(3) Supercomputing is used to run a variety of simulations, develop a turbine DT full life cycle decision support system, and perform quick interpolation and data extraction. These systems also enable online monitoring of physical parameters like flow rate and pressure. Machine learning is combined with the optimization procedure for data with significant comparison result curve deviation.

B. Finite element analysis: The finite element analysis (FEA) method is used in the simulation model in conjunction with real-time data from the assembly line. Innovative engineering methods and open-source development have also made it easier for field engineers and operators to use technology. As the digital twin is expanded to additional production lines, there is a good chance that Arçelik's manufacturing facilities may employ technology more frequently in the future. As a result, the overall cost of production and labor needs for refrigerators have decreased [3].

In [4], the use of a machine learning algorithm (decision tree) and digital twin technologies enables personalized medical care. The patient's historical and real-time data are both captured by the model. In order to forecast, monitor, and create a model that might be used for additional diagnostics, doctors, healthcare organizations, nurses, and patients will follow the observations. With the use of these technologies, effective and customized medical care may be created, and patients will have access to more individualized care. Cybersecurity is the main issue one could run into when utilizing digital twin technology. Data loss is a result of the rise in cybercrimes. The enormous amount of data is being gathered from multiple sources, all of which could be potential weak points. Cloud-based simulation software and storage can be utilized to address these difficulties and stop data loss and leakage. HIPPA-like regulations, for example, can be used to impose data governance. If properly implemented, these techniques may lower the likelihood of data loss.

In [5], the measured current was the input used by the FEA model. Temperature estimates at the same spot as the sensor-probed point were made in the simulation; readings had a significant correlation with dimensions (maximum error of 9.5%). Additional support for the DT theory came from simulations that looked at temperature distribution, torque profile, resistive losses, and stator copper conductivity—parameters that are challenging to measure but have a strong correlation with the motor's operating state. By demonstrating behavior that was consistent with theory and consistent with observations in the literature, these results provided support for the numerical model that had been created. The technique offers a tool that will aid in the monitoring of induction motor status in the future and produces accurate results under a continuous regime. The industry also benefits greatly from the advanced understanding because it means that the motor is only shut off when necessary for maintenance, which lowers expenses.

C. Computational fluid dynamics: Precision medicine's goal is to provide treatments that are customized for each patient. This goal is made possible by our growing capacity to collect vast data on each patient. In [6], the second enabling aspect for achieving this aim, in the opinion of some, is the capacity of computers and algorithms to learn about, comprehend, and produce a patient's "digital twin." Future treatments will consider more factors in addition to the patient's health right now and the information