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A review study on digital twins with artificial intelligence and internet of things: concepts, opportunities, challenges, tools and future scope

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Abstract
Recently, Digital Twin (DT) has a growth revolution by increasing Artificial Intelligence (AI) techniques and relative technologies as the Internet of Things (IoT). They may be considered as the panacea for DT technology for various applications in the real world such as manufacturing, healthcare, and smart cities. The integration of DT and AI is a new avenue for open research in the upcoming days. However, for exploring the issues of developing Digital Twins, there are interesting in identifying challenges with standardization ensures future developments in this innovative theme. This paper first presents the Digital Twins concept, challenges, and applications. Afterward, it discusses the incorporation of AI and DT for developing various IoT-based applications with exploring the challenges and opportunities in this innovative arena. Then, developing tools are presented for exploring the digital twins' system implementation. Further, a review of recent DT-based AI approaches is presented. Finally, a discussion of open research directions in this innovative theme is presented.

Keywords Digital Twins · Tools · Artificial Intelligence · Data Analytics · And Internet of Things

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1 Introduction

Over the past years, the concept of the digital twin was considered as a traditional expression, but recently it took a different way and was listed as one of the hot topics and top trends in the last several years. No doubt that a digital twin plays a significant role not only in cyber-physical systems design and operations but also in multi-disciplinary systems development to tackle fundamental barriers not addressed by the current, evolutionary modeling practices. DT provides several strategies such as AI, big data, and IoT to make a seamless connection between physical and virtual environments to simulate "what-if" scenarios.

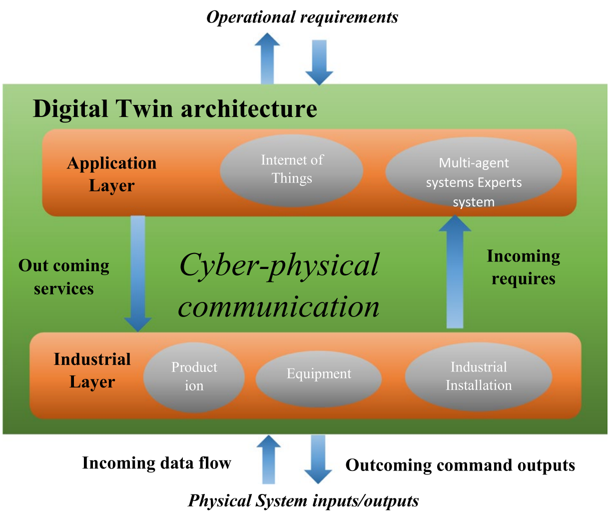
A digital twin is considered as a live view of a real-world system that monitors the state of its entities. Deeply, it is an environment that consists of a virtual and a physical machine. Each machine (model) is represented as a simulation, a mirror, or a twin of the other. So, the digital twin can list the life cycle of the physical entity which can be a human, an object, or a process [68]. Each digital twin is connected to its counterpart by a unique key, therefore a relationship between two entities can be established [48].

A digital twin is a partition of a Cyber-Physical System (CPS), which is a set of physical systems connected to virtual cyberspace through the network [11, 49]. The communication between a physical entity and its digital twin can be represented directly by physical connections or indirectly via a cloud system. Also, it can be a seamless connection and continuous data exchange [26, 88]. Three types of communication are the backbone of digital twin design [61]:

1. Physical and virtual twin communication.
2. Communicate with domain experts.
3. Communicate with different DTs in the surroundings.

Digital twin has three basic layers as shown in Fig. 1.Firstly, the industrial layer is responsible for complex systems and depends virtually on the digital twin environment and actually on the physical environment. Secondly, the application layer depends on

Fig. 1 Digital twin architecture



characteristics and contents concerning a virtual vision. Finally, the communication layer focused on cyber-physical connections [25].

Through the huge revolution of data technologies such as internet devices, big data, and cloud computing, DT becomes more applicable for many categories which are considered as the backbone of data analytics between physical and virtual environments. So, with the continuous application expansion, DT applications become more required and trend [36]. As illustrated in Fig. 5, There are several applications of digital twins such as the military, aerospace, agriculture, drilling platform, construction, automobile, electricity, smart city, manufacturing, healthcare, etc. [64]. Initially, a smart city is a witness to the DT development revolution. DT employment in the smart city is a significant opportunity for cities development. DT converts cities from traditional to digital cities with a smart visualization that appears in streets, underground and buildings. With the growth of DT across the advancements of IoT and AI technologies, updates the physical counterpart which reflects in the virtual space according to data transformation [69, 73].

Meanwhile, manufacturing is the key enabler of DT applications. Digital twin application of manufacturing is motivated for monitoring and tracking products to provide money and time. It allows the manufacturer to predict issues immediately by using high-level devices. Digital twin employment in manufacturing is the basis of product optimization in the processing stage and the entire life cycle. There are many examples of DT applications based on manufacturing techniques such as SAP, GE, Dassault, Microsoft, ANSYS, and TESLA [83]. According to unprecedented development by DT in health care, it turned impossible to become possible. Digital twin for humans will be the future exciting application that gives real-time analysis of the body. Nowadays, the simulation of certain drugs' affection and planning for surgical procedures performance are open research in health care. DT provides stakeholders in healthcare with the ability to simulate their specific environments in real-time and in the future. As well as, AI and IoT technologies can be employed with DT in this category for more decisions and predictions [80].

Paving the way to other applications, no doubt that DT has a significant role in the agriculture field [87]. Also, it was the power acceleration in drilling platforms. Fortunately, DT engagement with electricity was a supportive idea for data exchanges. Also, no one can deny DT's role in aerospace which appeared in systems performance. Civil engineering used a 3D platform to build a digital twin that supported construction and services [74]. In summary, This paper proposes a review study on the use of AI with DT for IoT-based applications as follows:

- Investigating of DT, AI, and the IoT concepts.
- Exploring challenges, requirements, and opportunities of IoT-based applications using digital twins.
- The state-of-art researches and recent studies of digital twins-based AI frameworks related to the Internet of Things applications.
- Highlighting recent development tools for building DT applications.
- Discussing challenges and opportunities of this innovative paper's subject.

The rest of this paper is organized as follows: Sect. 2 introduces literature review in the paper's subject. Section 3 presents Artificial Intelligence for DT while the Internet of Things technology and its applications are provided in Sect. 4. In Sect. 5 challenges and open research directions in the paper's subjects are presented while the development tools for implementing digital twins are provided in Sect. 6. Finally, the conclusion and open research points in this innovative theme are presented in Sect. 7.

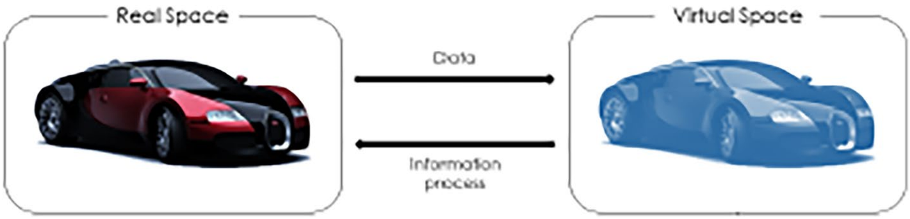


Fig. 2 Grieves' DT model

2 Literature review

In 1970, NASA forced some problems for reaching physical systems. Mirrored systems were the big motivation for these issues. The most popular example for such problems was a simulated design during the Apollo 13 mission [74]. The simulated element has an impressive performance when the oxygen tanks of the spacecraft Apollo 13 exploded. Such an example is considered as a digital twin ancestor, however, the model is not always synchronized because of the poverty of data consistency in real-time between the digital environment and its physical one.

In 2002, Michael Grieves has introduced the formal concept of DT. Grieves model was presented as three basic elements: physical object, virtual object, and the connection of data exchange from real to virtual space, as shown in Fig. 2 [29, 30]. The physical object has full responsibility for data control or exchange to converge between physical and virtual environments.

After ten years of Grieves' definition and the increasing knowledge about mirrored systems, NASA started the first whisper of DT development to serve its space assets. Now, NASA turned the whispers into talking and became the main pioneer of DT. It declared that it will improve performance in the aviation field [26, 76, 88]. Digital twin or (flying twin) is considered as a mirroring life system of its physical one.

In [27, 88, 89], a DT model is proposed by Tuegel et al. which predicts the aircraft life span which has an important role in U.S Air force aircraft's management. In addition, the Air force used digital twin concepts depending on the historical memory and their previous knowledge to gain "agility and tailor ability needed for rapid development and deployment'' [92]. Turning to researches that are found within the manufacturing area, as shown in Fig. 3, which illustrates paper subscribe in terms of healthcare, manufacturing, and

Fig. 3 DT Research Area Percentages

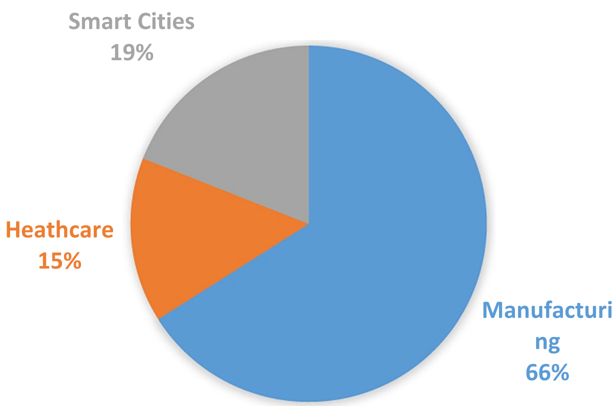


Table 1 Summary of impacted references

Citation	Number of papers
Springer	**7**
IEEE Xplore	**6**
IEEE Transaction	**3**
IEEE Access	**6**
IEEE Conference	**7**
Online Articles	**9**
Other	**69**

smart cities [23], in addition to Table 1 which concluded the published references which are used in this paper.

However, as summarized in Fig. 4, Ross's with Hewlett-Packard study using AI and IoT for DT avatars of people using several aspects. From a health perspective, DT can be combined with AI algorithms to study the affection on a person's health by using data integrity from physical element (Human) to virtual element (the replica) [69]. In addition, ElSaddik declared that DT has its potential role in the healthcare sector and it is not limited to the manufacturing environment [73] (Fig. 5).

In 2019, Laaki et al. introduced a prototype model of autonomous surgery using IoT and industry 4.0 for DT creation for patients by a remote surgery application through a mobile network. The prototype uses a robotic arm, VR with a 4G environment, to deliver precision surgery. They also discussed the challenges of prototype integration with DT and indicate how to facilitate the challenges of connectivity, integration, and multidisciplinary research [50]. Aligned with, Liu et al. who introduced a novel approach of DT and cloud technology combination to subscribe in the future delivery of healthcare by using IoTs technology and in-home sensors with an emphasis on use for the elderly. This combination increases the ability to predict patient problems more accurately [54].

On the other side, Björnsson et al. discussed a solution for Digital Twins construction based on high-resolution models for patients that are treated with several drugs to find the drug that has the optimal effection on the patient [10]. In [42] EL Azzaoui et al.

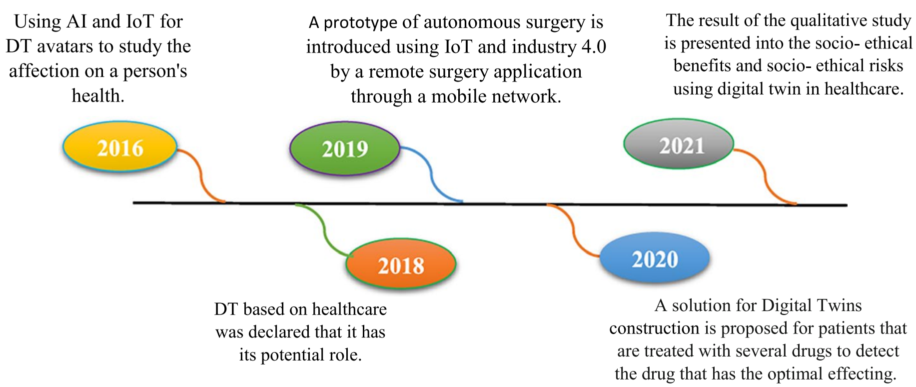


Fig. 4 The milestones of DT in healthcare

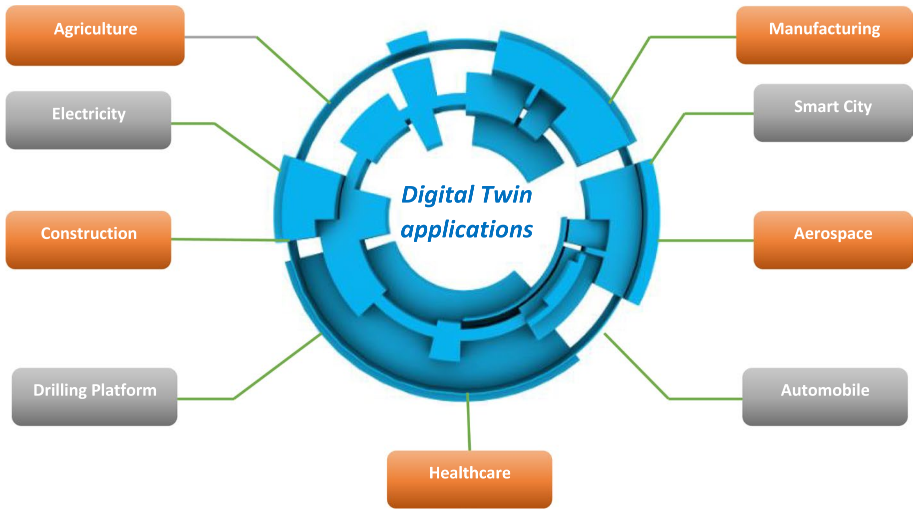


Fig. 5 Digital twin applications

proposed a DT framework based on a combination of two main sectors which are smart city and healthcare. The proposed framework aimed at high privacy and security by using Blockchain strategy according to several layers for system implementation.

Recently, Popa et al. presented the results of a qualitative study into the socio-ethical benefits and socio-ethical risks of using digital twins in healthcare. They also discussed what are the most important socio-ethical benefits and socio-ethical risks resulting from using digital twins in healthcare and how do stakeholders reflect these benefits and risks? [63]. Meanwhile, Elayan et al. introduced an implementation of an intelligent DT model based on machine learning algorithms for classifying, detecting, and diagnosing diseases such as heart problems [18]. While the smart city category had a revolution over the past several years, in 2017 Mohammadi et al., discussed a Smart City Digital Twin paradigm that increases the visibility of human interactions into the city as well as at the real-time interactions with virtual reality systems [59].

As shown in Table 2 which included the main points of the smart city category over the latest several years, Ruohomäki et al., in [70], presented a framework called “mySMARTlife” which uses IoT systems to establish a smart city based on DT. The case study depended on comparing and monitoring energy consumption which is based on the environment.

Fortunately, Jo et al. introduced a study that included the role of DT in the smart farm. Also, using DT was an effective challenge with industry 4.0 in the complex environment [40]. While in [15] Chen et al. presented a framework which is considered as a combination between DT and learning algorithms for providing warnings and instructions to minimize risks for drivers. On the other side, Pargmann et al., aimed at a new approach that depends on implementing DT via AR to integrate data in a single system. This study is applied to many wind farms in different countries by monitoring all wind farms in a parallel way [60].

Dembski et al. introduced a new novel approach which is a combination between virtual reality systems and the physical environment by using the tools of digital twins [17]. In [14] Castelli et al.presented a combination strategy between modeling,

Table 2 Categorical review of Smart cities

Papers	Review	Concept	Case Study	Simulation	AI	Industry 4.0	VR	AR	Cloud	Visualization and sensor ontology
Mohammadi, Taylor [59]	x	✓	x	✓	x	x	✓	x	X	x
Ruohomäki et al. [70]	x	x	✓	x	x	x	x	x	x	✓
Jo [40]	✓	x	x	x	x	✓	x	x	x	x
Chen et al. [15]	✓	✓	✓	✓	✓	x	x	x	x	x
Pargmann et al. [60]	✓	x	x	x	✓	x	x	✓	✓	x
Dembski et al. [17]	x	x	✓	✓	x	x	✓	✓	✓	✓
Castelli et al. [14]	x	x	✓	✓	✓	x	x	x	✓	✓
Wan et al.[93]	x	x	✓	✓	x	x	x	x	x	x
Petrova-Antonova, Ilieva [62]	x	x	✓	x	✓	x	x	x	✓	x
Schrotter et al. [75]	x	x	✓	✓	x	x	✓	✓	✓	x
Austin et al. [8]	x	x	✓	x	✓	✓	x	x	x	✓
Ford, Wolf [22]	x	x	✓	✓	✓	✓	x	x	x	✓
Lu et al. [55]	x	x	✓	✓	✓	✓	x	x	✓	✓
Petrova-Antonova, Ilieva [61]	x	x	✓	x	✓	x	x	x	✓	✓
Jonathan et al. [41]	x	x	✓	✓	✓	✓	x	x	✓	✓

simulation, and learning tools using digital twin representation using city infrastructure and citizen interactions. While Wan et al. presented a new approach for Cambridge DT system development which depended on city infrastructure and other technologies such as simulation and AI [93]. In [62], Petrova-Antonova, Ilieva proposed a framework of a virtual city that introduced a new strategy for system prediction based on decision-making techniques.

Schrotter et al.introduced the Zurich digital twin which can provide the street visualization, underground, and buildings in more detail to improve data analytics and digital twin framework [75]. Austin et al.discussed a challenge of digital twin architecture in the smart city which supports machine learning approaches. Machine learning plays an effective role in this study in data collection, processing, and decision making [8]. Meanwhile, Ford and Wolf Introduced a new vision of SCDT system modification based on simulation techniques for disaster management [22]. While in [55] Lu et al. implemented a new framework based on a real design which achieved a huge challenge of DT development from buildings and city perspectives.

Recently, Petrova-Antonova, and Ilieva, aimed a framework for modeling a digital city based on a digital twin strategy. The study followed the sequence of digital twin architecture using a decision-making algorithm and upper-level ontology [61]. Jonathan et al. presented a new challenge for the digital twin approach using the IoT in the category of a smart city. This use case aims to enhance data consistency, mapping, and methods in digital cities environments [41].

Turning to manufacture which is considered as the pioneer of DT categories. Beginning with 2018, in [66] Qi et al., presented a combination study between DT and its employment in services of manufacturing. This convergence is a potential expansion for DT functions. Also, He et al. introduced a review that indicates DT applications of industrial processes based on IoT strategies and investigates new challenges for pen research in this area [33].

Sivalingam et al. proposed a novel approach to predict the useful remaining power converter of wind turbines using wind turbine applications along with digital twin strategies [78]. Also, Qi and Tao [65] presented a new different review of DT concerning big data strategy based on manufacturing settings. Fortunately, they proposed a comparison study between DT strategies to emerge engagement between technologies.

But this is not the end, in [84], Tao, introduced a comparison study between the digital twin and Cyber-Physical systems (CPS) in a manufacturing environment. While in [85] Tao took a different way based on the combination between Digital twin and industry techniques. Both [84] and [85] shared the same technologies such as big data, IoT, cloud, and AI. As well, in [86] Tao covered the basics of DT components, concepts, architecture, industry applications, challenges, and open research.

Aligned with previous studies, Bilberg and Malik, introduced a DT simulation model of an assembly cell which is controlled by a human–robot by combining assembly methods between physical and digital systems [9]. While in [57] Mandolla et al. presented a new DT model for the aircraft industry based on blockchain facilities. This study introduces answers for securing data resulting from manufacturing operations and provides solutions for building a secure manufacturing infrastructure.

This paves the path toward Min et al. to produce a new DT model based on industrial IOT, data exchange, and machine learning techniques. Also, this paper is a case study that introduces a new framework for economic enhancement through the production process. This framework examination was executed in a real factory to ensure effectiveness and value [58].

On the other side, Shangguan et al. presented a new hierarchical model of DT which can support complex systems. The new model deals with CPS dynamically and is still connected during the entire life cycle [77].

Fortunately, Karadeniz et al. in [47] presented a new 3D digital twin model named eGastronomic things which are considered as a real case and a combination between the concept of DT and industrial food technologies. While Xu et al. investigated a new 2-phase DT model for fault diagnosis detection depending on deep learning algorithms. The new system aimed to increase autonomous and system complexity [96].

According to 2020, there are different perspectives in manufacturing strategy as in [21] Shao, Helu introduced a new study that explained the main aspects for DT construction, and how to emerge these perspectives to generate a guidance framework for DT development.

As well as Lechler et al. proposed a new structure DT model which follows the same scenario of standard DT structure in definition and functionality and can be used for different applications [51]. As illustrated in Table 3 which summarized contributions of manufacturing researches, Zheng, and Sivabalan discussed a framework of the 3D printer model which depends on the traditional CPS system of DT that includes a physical layer, data extraction, consolidation layer, cyberspace layer, and interaction layer [98].

While Aheleroff et al. in [2] focused on a new strategy which is considered as a combination between industry 4.0 techniques and a comprehensive reference model to overcome Challenges of DT applications. In addition, Azamfar et al. overcame the gap between industry 4.0 and smart manufacturing by facilitating the transformation between them. They constructed a new DT architecture which consists of 5C-CPS and deep learning algorithms [52].

Recently, Bai introduced a review that employs AI technologies in DT systems especially in manufacturing environments [32]. As well, in [53] Liu et al.presented a prototype of a DT manufacturing system based on the CMCO model. The results ensure that the proposed system is more applicable and efficient. According to [94], Wang et al.proposed a new DT structure for allocating shared manufacturing resources in the DT service model for achieving effectiveness and efficiency validation.

3 DT based on AI

In 1956, the Artificial Intelligence (AI) revolution was officially introduced. But, no one could expect the huge capabilities, effectiveness, improvement, affection, prediction, and achievement of AI technologies. Artificial Intelligence (AI) is considered as the umbrella of many categories such as Machine Learning (ML) and Deep Learning (DL) algorithms. Fortunately, AI employed high-dimensional data strategies like big data and cloud computing [20].

With the growth of AI integration models, the way was smoothed for one of the fundamental parts of recent strategies, that is the Digital Twin. A combination of DT applications and AI models is a magical choice for researchers for more challenges and opportunities [12].

While DT systems are intelligent, it must be realized that they are not independent because new features and updates of physical assets need to be tested, especially in diagnosis cases. So, DT based on AI just supports human skills. In the last few years, many types of research have been published specifically for DT systems based on AI strategies, however, none of them covered all aspects of data connections and their relative DT models. Table 4 summarized some DT publications which are purely published recently for AI perspective.

Table 3 A Summary of digital twin researches in the manufacturing category

Research Work	Year	Contribution Summary
Qi et al. [66]	2018	The paper highlighted an encapsulation between DT and manufacturing according to service platforms
He et al.[33]	2018	The paper reviewed DT industrial applications based on IoT techniques. As well as, discussed challenges and open research about this area
Sivalingam et al [78]	2018	The paper discussed a novel approach for wind turbine prediction based on the DT framework using maintenance strategy
Qi, and Tao [65]	2018	The paper is a review that introduced digital twin concepts and big data technologies based on manufacturing techniques
Tao et al. [84]	2018	The paper proposed new frameworks of Digital twin to produce a new product using new aspects such as design, service, and manufacturing
Tao et al. [85]	2019	The paper is a review that discussed the difference between the Digital twin and CPS from different perspectives
Tao et al.[86]	2019	The paper reviewed the components of DT, concepts, architecture, industry applications, challenges, and open research
Bilberg and Malik [9]	2019	The paper aimed at a simulation model of a new digital twin system of a human–robot
Mandolla et al [57]	2019	The paper focused on manufacturing operations in the aircraft industry in which digital twins can be created through the utilization of Blockchain solutions
Min et al.[58]	2019	The paper proposed a new approach for DT creation based on industrial IOT, data exchange between physical and digital environments, and machine learning to optimize the proposed model
Shangguan et al [77]	2019	The paper provided a new hierarchical model of DT which facilities data storage from the lifecycle of products. Also, an application of industrial robots is proposed for efficiency coordination
Karadeniz et al.[47]	2019	The paper presented a new 3D digital twin model named eGastronomic things based on simulation and augmented reality(AR) to control the functionality of data DT and their counterpart
Xu et al. [96]	2019	The paper investigated the 2-phase DT model for fault diagnosis detection by deep learning algorithms
Shao, Helu [21]	2020	The paper indicates the main characteristics that must take into account for digital twin construction
Lechler et al. [51]	2020	The paper proposed a new DT structure model and compared it with a standard DT model
Zheng, Sivabalan[98]	2020	The paper discussed a new approach to the 3D model system based on the traditional CPS system of DT
Aheleroff et al. [2]	2020	The paper proposed a new approach of DT as a service under the supervision of the industry 4.0 environment

Table 3 (continued)

Research Work	Year	Contribution Summary
Azamfar et al. [52]	2020	The paper investigated a DT framework that depends on a new architecture based on deep learning and 5C-CPS
He, Bai [32]	2021	The paper is a review of intelligent DT according to manufacturing perspective
Liu et al.[53]	2021	The paper presented a new prototype of a DT manufacturing system based on CMCO model
Wang et al. [94]	2021	The paper investigated a new DT architecture based on allocating shared manufacturing resources in the DT service model

Deeply, Talkhestani et al. highlighted DT features, components, and architecture according to a new intelligent DT automated system. AI was the main part because it was the autonomy stakeholder in the entire system [6]. In another study, Mukherjee, and DebRoy presented a new strategy based on intelligent methods such as machine learning and big data techniques to reduce trial and error testing for the production and design of digital twin 3D printing models. As well, this study discussed how to reduce time complexity which affects the efficiency of printed elements [6]. While in [91], Uzun et al. succeed to build a new strategy by separating the DT model into small sub-models based on flight settings using machine learning platforms and comparing the performance with an aircraft model.

Flowingly, Alexopoulos et al. presented a new DT approach based on machine learning models which is more helpful and achieves development for intelligent systems [3]. Turned to Rasheed et al. who aimed a review of DT based on AI modeling challenges and techniques for system development [67]. Also, Wu et al. discussed a new case study of the DT battery model by using intelligent landscape [95]. Fortunately, Jazdi et al. proposed an enhanced DT system by implementing an intelligent physical asset and its avatar by employing AI technologies on the DT environment [38].

Recently, in 2021 Farhat et al. aimed to detect the fault diagnosis of machines by creating a simulated DT model which is emerged with machine learning techniques for accurate detection and classification [19]. Meanwhile, in [4] they raised controversy about 3D bioprinting model construction by building a training dataset based on big data approaches and then creating DT for a human to achieve a powerful prediction by using a hybrid strategy of digital twin and big data together.

There are several researches that can be added as a methodology to our extension work of digital twins system such as what presented in 2016 by Madheswari and Venkateswaran for using a particle swarm optimised image fusion framework in Discrete Wavelet Transform domain (DWT) that combines the thermal image with the visual image to obtain a single informative fused image [56].Smoothly, in 2017 they discussed a framework which is considered as a new optimized contrast enhancement algorithm for color images that improves visual perception of information [43].

Paving the path, in 2019 Kanmani and Narasimhan discussed a new fusion algorithm that optimally combines spectral information from MS image and spatial information from the PAN image of the same scene to create a single comprehensive fused image [44]. Also, they proposed a new strategy by using Particle Swarm Optimization (PSO) algorithm in NSCT domain. The proposed method is tested on five set of standard test images and the fused image contains the more information about contour of bones and structure of tissues that can be used to make accurate clinical decisions [45]. In addition to in 2020 the same authers introduced a novel which ensured that face recognition techniques have significant performance improvement in recognition accuracy [46].

4 DT based on IoT

As shown in Fig. 6, the IoT concept is called on every device that can connect to the internet so, it can be also known as the internet of everything. IoT is officially introduced by Kevin Ashton who showed off his vision in 2009 [7]. This idea is objected to giving developers all facilities for tracking and monitoring operations which led to a smarter world.

With the obvious growth that IoT technology achieved over the years. The number of devices has reached the top since 2018. So, 2025 will be a witness of a huge revolution in this approach as a prediction. Figure 7 illustrates the IoT devices revolution in the last years [82].

Table 4 A Summary of AI-based DT approaches

Research Work	Year	Contribution Summary
Madheswari and Venkateswaran [56]	2016	The paper discussed an optimised image fusion framework to combine thermal and visible images to produce a single informative fused image
Madheswari and Venkateswaran [43]	2017	The paper introduced an optimized contrast enhancement technique based on particle swarm optimization for color images
Talkhestani et al [6]	2019	The paper introduced a new intelligent architecture of a digital twin automated system
Mukherjee, DebRoy [6]	2019	The paper focused on using intelligent methods for trial and error testing reduction on the digital twin of the 3D printing model
Uzun et al [91]	2019	The paper introduced a comparison study between digital twin flight mode and the performance of an aircraft model based on machine learning fashions
Kanmani and Narasimhan [44]	2019	The paper presented a new algorithm which is a combination between multispectral information and PAN images to produce a single comprehensive fused image
Kanmani and Narasimhan [45]	2019	The paper proposed a new framework which is based on non-subsampled contourlet transform (NSCT) image fusion by combining CT and MRI images
Alexopoulos et al [3]	2020	The paper proposed a framework of a DT system based on machine learning models
Rasheed et al [67]	2020	The paper introduced a comprehensive review of DT challenges and technologies based on AI, specifically from modeling scope
Wu et al [95]	2020	The paper presented a new framework of the battery model based on intelligent approaches for DT battery construction
Jazdi et al [38]	2020	The paper introduced a case study of a combination between DT technologies and AI automation systems
Kanmani and Narasimhan [46]	2020	The paper presented and compared three different fusion schemes for combining thermal and visible imagery for the purpose of face recognition
Farhat et al [19]	2021	The paper drew the roadmap of the DT simulated system based on machine learning approaches
An et al [4]	2021	The paper proposed a new vision of 3D bioprinting model from Digital twin and machine learning perspectives based on big data technology

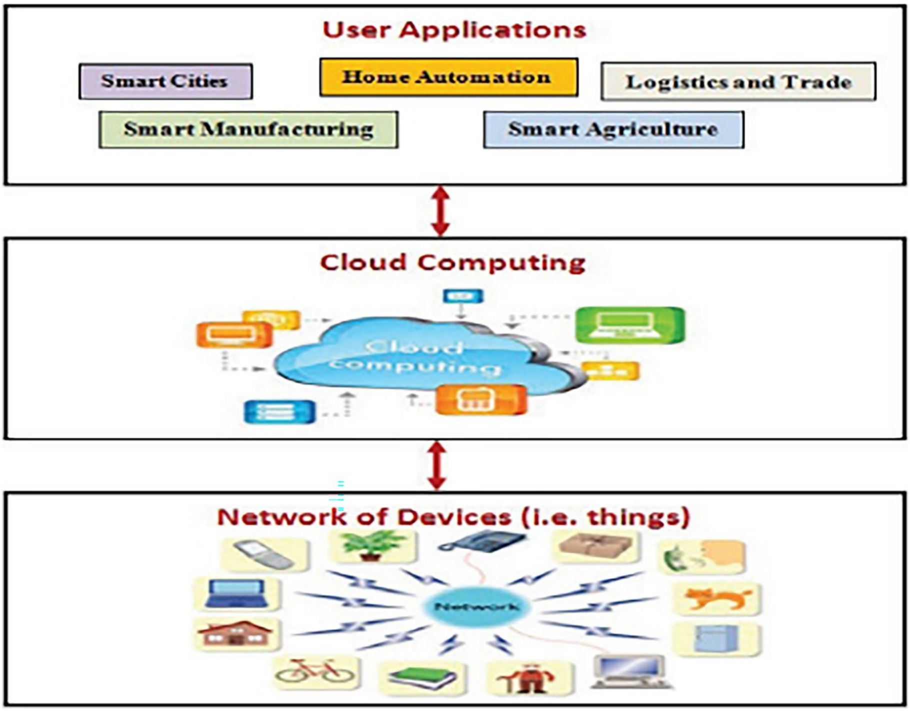
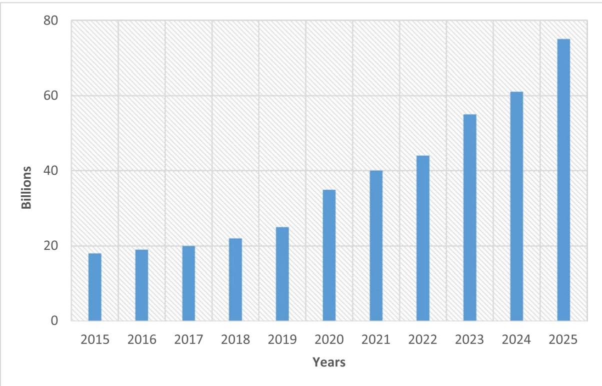


Fig. 6 Internet of Things (IoT) System

Now, the spreading of IoT devices is considered as the backbone of several applications such as manufacturing, construction, healthcare, communication, smart cities, and human life.

But it was not the end, Ashton continued the series of successes by introducing the Industrial Internet of Things (IIoT) which is derived from IoT fashion. IIOT is similar to the IoT strategy with some additional techniques for industrial approaches. Meanwhile, Boyes et al. presented several IIoT definitions that strong IoT and IIoT situations concerning other settings [13]. Now, the way was paved for industry approaches development which is an entrance of IoT within the industrial revolution as in Fig. 8 [23].

Fig. 7 IoT Devices Growth



Going forward Digital twin scope, IOT becomes one of the fundamental parts of DT studies which has a full dependency on data connection between physical and virtual spaces. IoT technology based on DT builds its strategy according to data sensors that understand the current state of a physical entity, reacted to changes, and any changes related to connections between environments. According to IoT revolution based on DT, researchers documented a lot of researches in this category specifically over the past few years as summarized in Table 5.

In 2019, Hofmann, and Branding introduced a DT system based on simulation platforms to optimize dispatching policies, application employment, and integrate sensors in real-time [35]. In addition, in [79] Sleuters et al. presented a new method for digital twin development based on automatic behavior of large-scale IoT systems. Fortunately, Hinchy et al. proved that DT technology can be implemented in manufacturing platforms by using low-cost IoT devices such as microcontrollers and PLCs [34].

On the other side, Gehrmann, and Gunnarsson focused on synchronization metrics to converge between the actual physical design and desired DT requirements. The system will be surrounded by high-level security which increases performance and protection [24]. Saad et al. proposed a framework based on increasing the IoT security of a physical system. According to the results, the authors succeeded to build a new DT model which improved system protection[72].

While Angin et al. introduced a new DT framework based on wireless sensors and cloud computing. The results indicated that the framework achieved a low-cost agriculture system, used algorithms to detect plant diseases, and increased yield production [5]. Also, Saad et al. introduced another DT model of CPS based on two main strategies: IOT which is responsible for system communication, cloud technology which is used for system implementation in the virtual environment [71].

Recently, Jiang et al. proposed a comprehensive DT model which focused on serving data, model, and service. This framework passed through several layers one of them is the IIoT layer to improve the connection performance between physical and virtual spaces [39]. While Granelli et al. took another path by focusing on IoT qualification and assessment based on a new DT structure by using several ways such as IOT system configuration, and behavior evaluation. In this study, the DT framework has a vital role in measuring resources variation and consumption over the network [28].

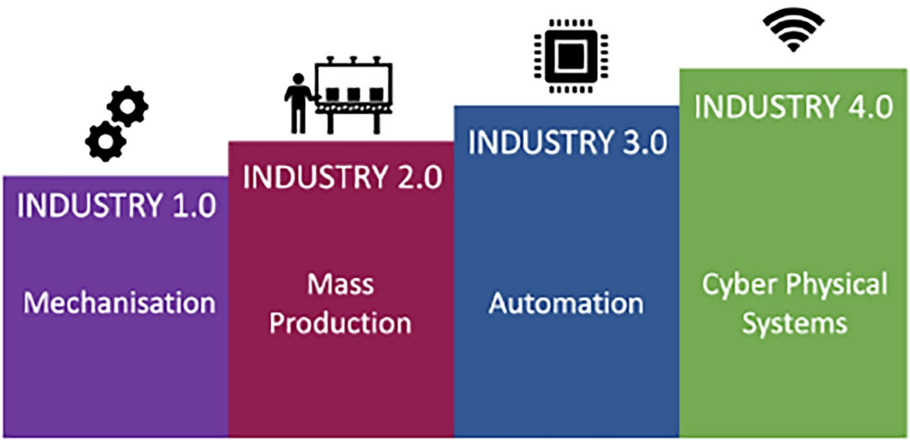


Fig. 8 Industrial Revolution

Table 5 A Summary of IoT-based DT approaches

Research Work	Year	Contribution Summary
Hofmann, Branding [35]	2019	The paper introduced a digital twin system for dispatching policies optimization based on the simulation performance
Sleuters et al [79]	2019	The paper presented a new framework for DT development according to large-scale IoT systems behavior
Hinchy et al [34]	2019	The paper presented DT implementation based on low-cost manufacturing platforms
Gehrmann, Gunnarsson. [24]	2020	The paper aimed to build a synchronized system that achieves the convergence between actual design and desired DT requirements based on high-security elements
Saad et al [72]	2020	The paper introduced a new DT model of a physical system based on IOT technology for physical attacks protection
Angin et al [5]	2020	The paper discussed a new DT framework of a low-cost agricultural system
Saad et al [71]	2020	the paper proposed a new DT model of CPS based on IOT connections and cloud technologies which are used to serve several applications
Jiang et al [39]	2021	The paper introduced a comprehensive model (DMS model) which applied through IIOT technology
Granelli et al [28]	2021	The paper introduced the DT structure for IoT qualification and assessment

5 Challenges and opportunities

No doubt that DT, AI, and IoT challenges have run in parallel over the last few years. Meanwhile, several challenges related to IoT, and data analytics have a common factor which is a Digital twin. Beginning with, the impressive infrastructure of Digital twin is one of the biggest challenges of DT fashion. Without a strong infrastructure, the system will not able to achieve specific goals such as high performance and effectiveness [23].

Turning to data is considered another challenge according to the digital twin environment. It depends on data transfer and connection between the physical and virtual world. Data should have high quality, free of noise with an uninterrupted constant data flow. If data suffered from poverty and inconsistency, it will force low performance from DT because of the poor and missing data. Devices need analysis and planning for identifying the right data which can be collected for effective usage of DT [20].

In the industry environment, security and privacy based on DT play a significant role, firstly because of the huge amount of data that can be used and secondly, the risk that is posed to the sensitive data system. To overcome that challenge, enabling technologies for DT should follow updates and current practices in privacy and security rules. These rules are contributed by tackling trust issues with DT. The challenges based on trust in DT prevail from interpreters' and user points of view. Besides, there is another challenge that is always ignored. It is the trust challenge that needs a lot of effort from organizations by explaining DT technology from a fundamental level and DT benefits. Such challenges should keep in mind[10].

Despite the DT technology revolution, caution is required for its challenges. DT needs a solid foundation for IoT infrastructure to ensure that organizations will make use of DT. It is also a challenge to think that DT will only combat the current trends. The DT's advantages and disadvantages should be discussed to ensure appropriate action that will be taken during system development [15, 28].

In addition to previous challenges, there are also specific challenges related to DT construction and modeling. Concerning DT modeling, it is still suffering from the poverty of standardization. Initially, the simulation design of DT needs to be in a standard category because standardization can realize the environment and make use of information flow between development stages and DT implementation[10, 15].

With the breakthrough of Industry 4.0 and digitalization which growing rapidly in parallel with the technologies revolution at different rates, a few small challenges are generated based on data connectivity and exchanges. For instance, DT and IoT devices should be homogenous with each other. Surely, with the growth in different rates, new challenges will be generated and taken into account especially according to weak aspects and drawbacks[79].

6 Tools for Digital Twins Development

Several platforms are implemented specifically for the digital twin environment. These platforms are divided into categories according to services and stages. Each study described DT tools from their perspective [64]. This paper will represent DT tools in a more general vision as shown in Fig. 9.

6.1 Physical world platforms

Physical world platforms have two categories which are tools for physical entity recognition and tools for controlling physical entity. When a physical entity recognized data, in this case, DT converts data into operations and behavior which required specific software to perform operations [1, 81, 90]. The second platform category is controlling physical entity which completely depends on the feedback information. It translates virtual space state, analysis, and processes to its counterpart. Tools related to the physical environment are summarized in Fig. 10.

6.2 DT modeling platforms

DT modeling platforms provide several domains and capabilities for modeling structure. one of the important facilities introduced is virtual system deployment and validation [1]. DT modeling tools are divided into five main categories. Firstly, the geometric platform is based on the analysis and planning of system structure [16]. Secondly, the physical modeling platform is based on physical system construction and characteristics. Thirdly, the behavior platform is responsible for external factors and improving DT performance. Finally, the ruling platform which based on laws modeling and behavior rules of physical systems. Figure 11 illustrates software for each category in detail.

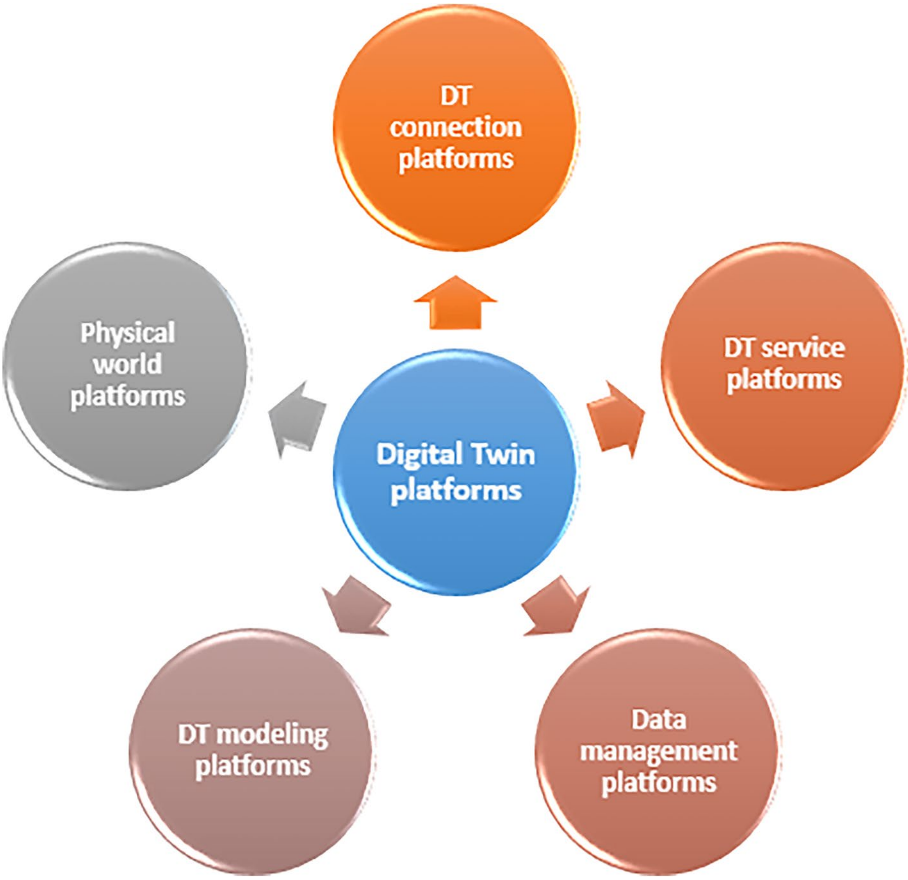


Fig. 9 Digital twin platforms

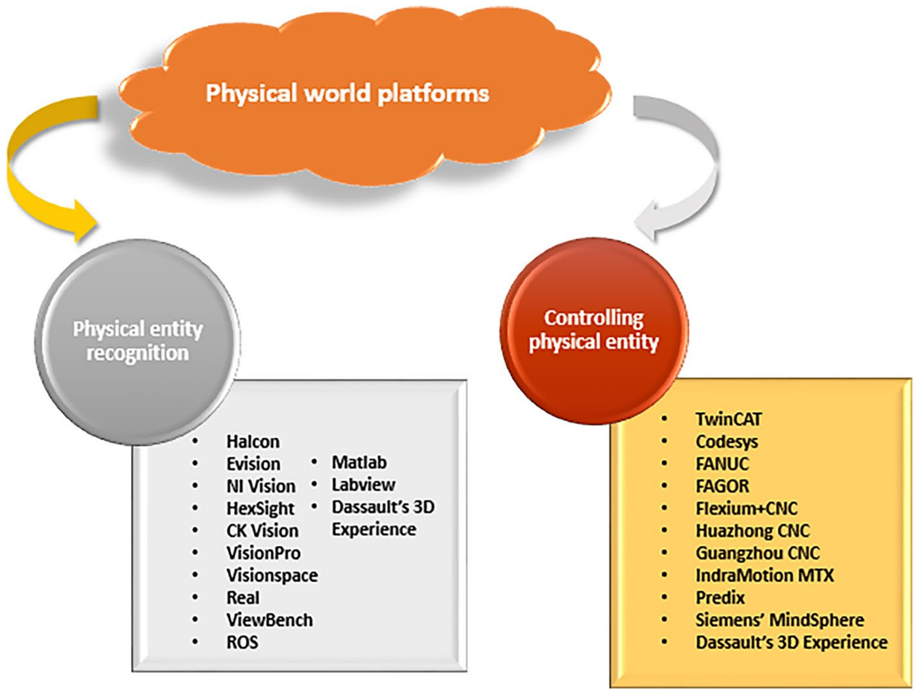


Fig. 10 Physical-world platforms

6.3 Data management platforms

As usual, data is the backbone of the DT environment. The data management platform is the stakeholder of several small categories which include a lot of data software systems. Starting with data collection which is used for data detection and checking data effectiveness for high DT performance. Turning to data transmission that is used for data completeness and trustiness in real-time. While data storage indicates data requests during data transmission operations. Meanwhile, data processing is responsible for data availability and confusion detection. Also, data fusion has a powerful role in data processing for diagnosis and qualification. In addition, Data visualization is helpful in data holding, capturing, and monitoring in real-time for stakeholders. All of the related tools are shown in Fig. 12.

6.4 DT service platforms

As shown in Fig. 13, DT service tools are divided into several types such as service platform, and application platform. Service platform provides combining technologies such as AI, IoT, and big data [97]. The application platform is considered as a monitor system of service, diagnostic, optimization, and simulation platforms. Optimization platform which is helpful for system optimization, high performance, and cost reduction. Similarly, simulation platform which is used internal software approaches for machine vibration reduction. As well, the diagnostic platform is used for prediction and analyzing approaches [31].

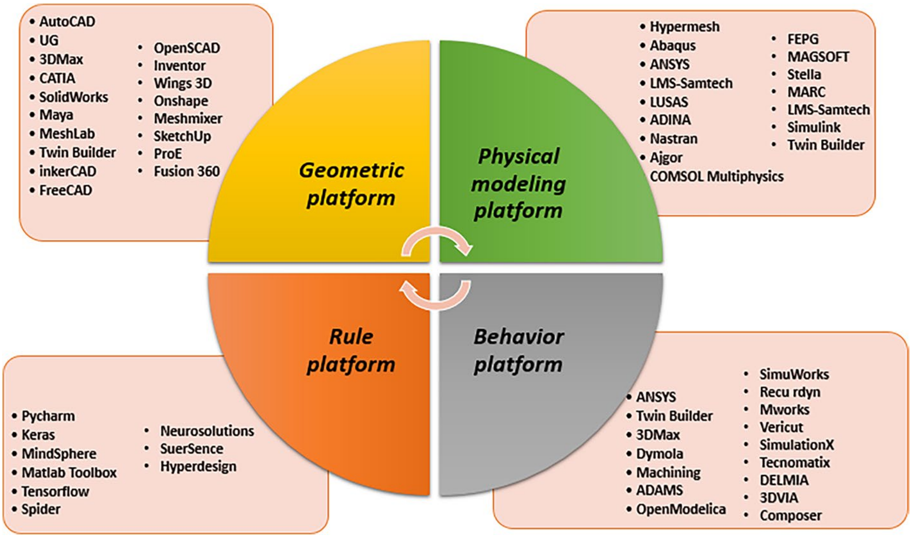


Fig. 11 DT modeling platforms

6.5 DT connection platforms

DT connections are a connection between each part in the DT environment. It is a roadmap between the physical and virtual worlds [16]. DT connections depend on different technologies such as IoT which control availability, exchanges, and services between corresponding entities[37]. Fortunately, these connections are necessary for several aspects performance optimization, problem prediction, and system development. Programs are summarized in Fig. 14.

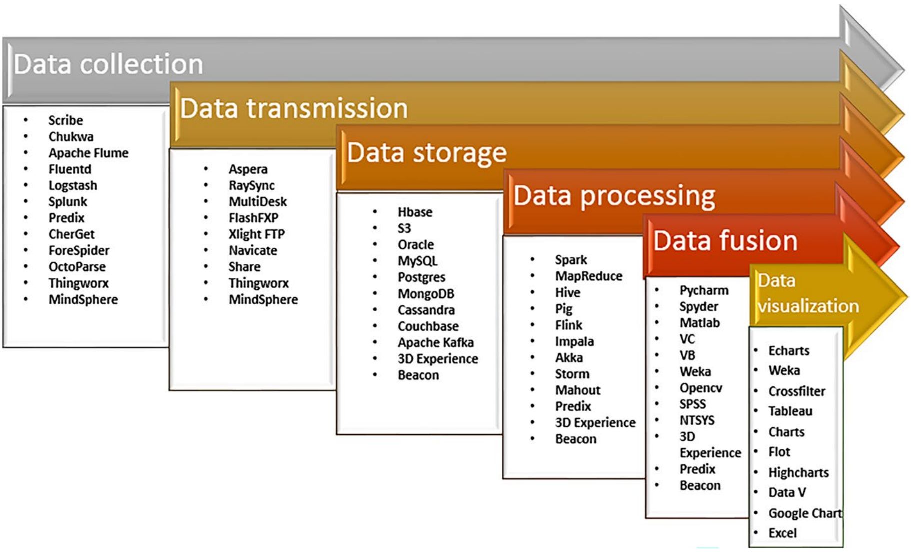


Fig. 12 Data management platforms

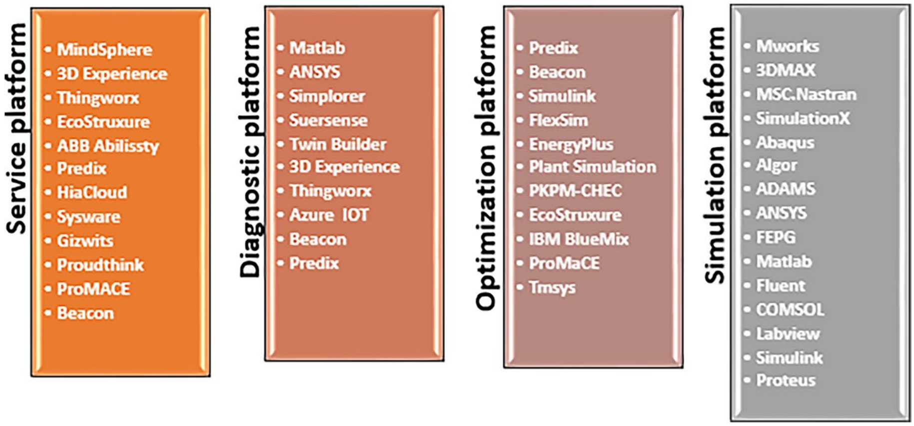


Fig. 13 DT service platforms

7 Conclusion and future scope

In summary, this paper introduced the Digital Twins and AI concepts, challenges, and applications. Moreover, it explored the integration of AI and DT for developing various recent IoT-based applications. The developing tools are given also for exploring them for implementation of the digital twins' system. Besides, researchers' efforts for digital twin development, in addition to challenges and opportunities which are currently forced. As future open points in this interesting subject, there is a plethora of open research work as follows:

- Creating novel frameworks and models for the creation of DT models for early prediction and diagnosis of critical errors in Industrial IoT applications.
- Using the help of Blockchain in building secure and accurate DT-based IoT models for real-time detection of criminals and attackers especially for Critical Industrial Control Systems(ICS) such as electrical and power networks.

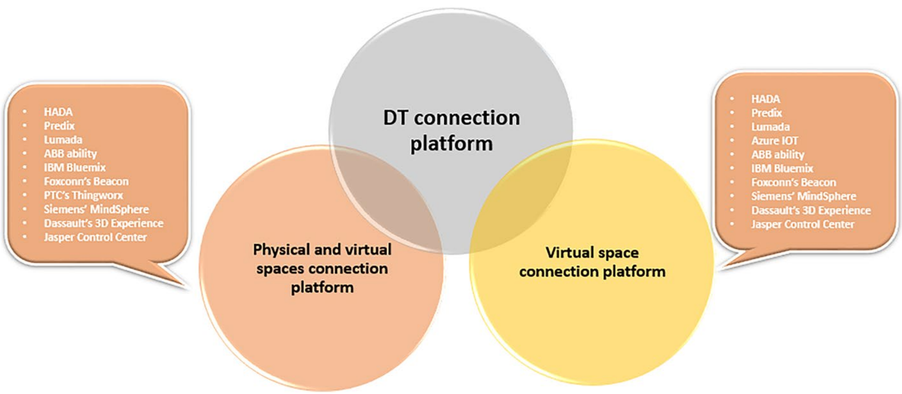


Fig. 14 DT connection platforms

- How to combine AI and DT technologies based on their requirements. By considering developing a new method that can support the crucial requirements of entirely IoT applications.
- Build a cloud-based DT processing environment for handling enormous data using big data platforms such as Apache Spark.
- Explore Blockchain, big data analytics, and DT relationships and how big data analytics can easily and quickly handling of massive generated data from DT-based IoT applications in a secure manner.

Data availability Data available on request from the authors.

Declarations

Conflict of interest The authors have no conflict of interest.

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