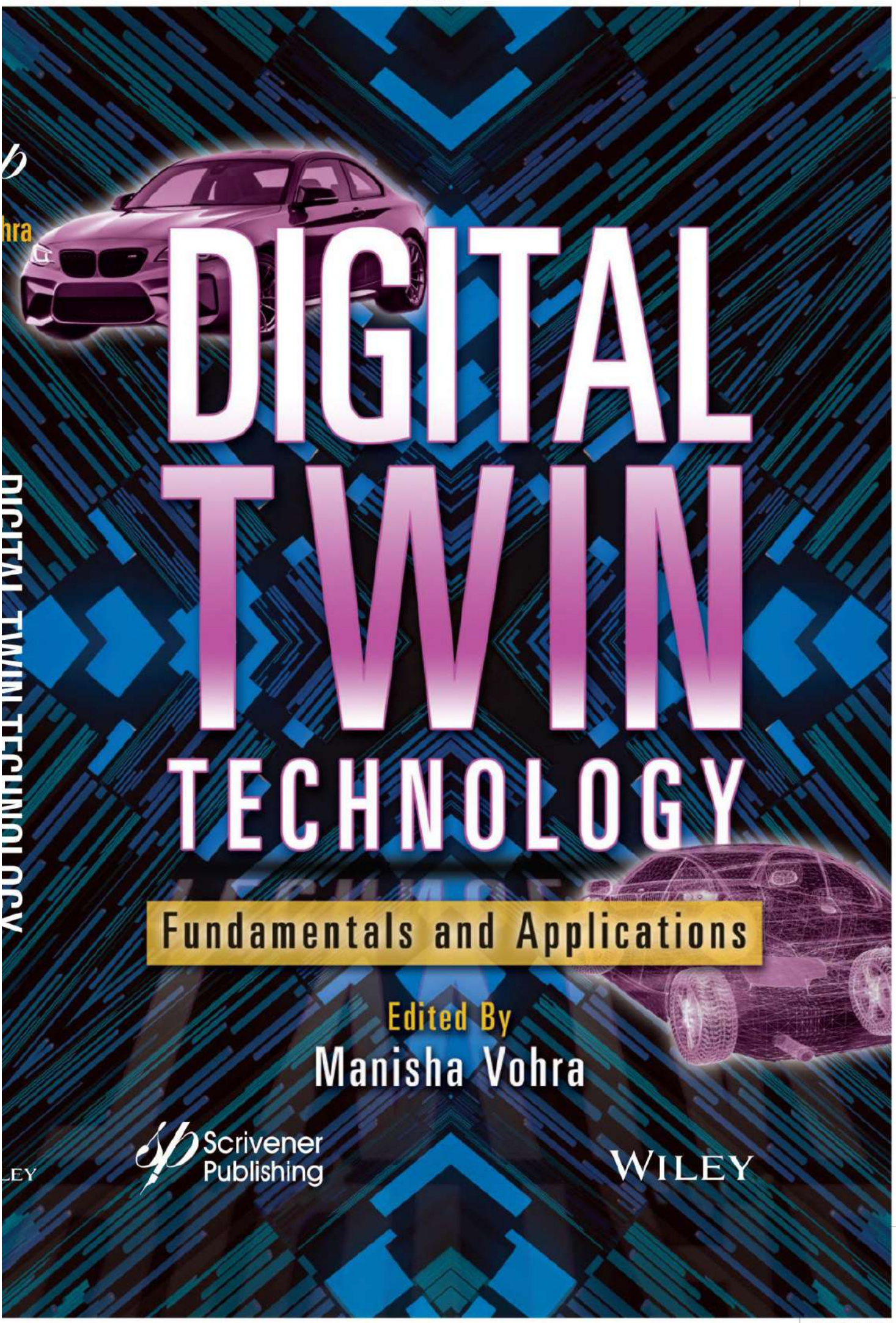

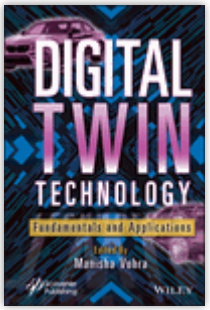

Digital Twin Technology: Fundamentals and Applications

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About this book

DIGITAL TWIN TECHNOLOGY

The book lucidly explains the fundamentals of digital twin technology along with its applications and various industrial real-world examples.

Digital twin basically means a replicated model of any object or product in digital form. A ... Show all

Table of Contents

Export Citation(s)

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CHAPTER 14

Possibilities with Digital Twin (Pages: 219-232)

Vismay Shah, Anilkumar Suthar

Summary | PDF | References | Request permissions

CHAPTER 15

Digital Twin: Pros and Cons (Pages: 233-246)

J. Prakash

Summary | PDF | References | Request permissions

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Index (Pages: 247-252)

First Page | PDF | Request permissions

7

Digital Twin Applications and Challenges in Healthcare

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Abstract

Digital twin is an efficient technology. With digital twin evolving, various sectors can gain advantages from it. The advancement of the Internet of Things (IoT), has helped digital twin to evolve. A digital twin is identical in all aspects with its original counterpart and can be used in running simulation, predicting errors of objects, products, etc. In connection to the healthcare sector, digital twin can help in it in different ways. Just like how it can provide advantages to various sectors, namely manufacturing sector, aviation sector, etc., similarly it can provide advantages to the healthcare sector as well. Using this technology, the healthcare sector can benefit largely. In this chapter, a literature based survey is presented on the application of Digital Twin and its challenges in healthcare. It is found that there are different applications of digital twin in healthcare sector. A real life example of the use of digital twin in healthcare application is also discussed and explained briefly in this chapter. The challenges digital twin face in the healthcare are also not just briefly discussed but also explained in this chapter.

***Keywords*:** Digital twin, healthcare, IoT, data security, medical devices, data privacy

7.1 Introduction

Healthcare sector is a very essential sector. Healthcare is of great importance. This sector has been evolving with many technologies being brought

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and introduced for application in this sector. This has led to the path of advancements in healthcare sector. For example, the introduction and inclusion of telemedicine in healthcare has made healthcare services like diagnosis, consultation, monitoring all this possible remotely.

Various more advancements are seen in healthcare like the introduction of precision medicine, inclusion of robotics for surgery related applications as well as some other applications in healthcare, wearable devices for heart-rate monitoring, etc.

With many technologies being introduced and leading towards the path of advancements in healthcare sector, there is yet another technology which can lead towards the path of advancements in healthcare sector. It is the digital twin technology. It is having great potential to be useful and beneficial in the healthcare sector.

7.2 Digital Twin

The digital twin is receiving an increase in interest from the academic perspective and the industrial perspective as well [11]. The digital twin, means a system's digital counterpart along its lifecycle [15].

Conceptually, a DT mimics the state of its physical twin in real time and vice versa [1]. A digital twin, just similarly like a virtual prototype, is a dynamic digital representation of a physical system [8]. The digital twin in its original form is described as a digital informational construct about a physical system, created as an entity on its own and linked with the physical system in question [13].

Digital twin concept aims to enable the observation of the behavior of the whole system and also along with it, the digital twin concept aims to enable the prediction of the system behavior during its utilization [6]. Digital twin lets the virtual entities to exist simultaneously with the physical entities [10].

The digital twin was first spoken about in a public event in the year 2002. National Aeronautical Space Administration (NASA) first used digital twin in Apollo 13 Program in 1970. NASA has also released a paper titled "The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles" [27] which is a very helpful documented work on Digital Twin. It has set a milestone for the development and research on Digital Twin. The definition of digital twin given in [27] is as follows:

"A Digital Twin is an integrated multi-physics, multiscale, probabilistic simulation of built-in vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" [27].

With recent developments, many researchers have presented their views on digital twin technology. There are also various definitions given by different researchers defining digital twin technology.

Digital Twin technology connects digital and the physical world. Digital twin is a digital copy of an original object in the physical world. In digital twin technology, virtual models are formed which are the copy of the original object in the physical world. These virtual models have the task of mimicking the original object.

To make digital twin there is integration of the original object with virtual models or virtual twin which are made same as the original object whom they are mimicking. After integration live data is sent from original object to virtual twin. As a result, the digital twin is created of the original model. The behavior of the original object can be studied with digital twin.

It can predict failure or breakdown or problem in advance only, before it happens, which helps in preventing the failure, breakdown or problem. With this technology, problems, breakdown can be prevented so there will be overall cost savings and avoidance of downtime as well.

Digital twin model needs very large amounts of information as well as computing capability [4]. Digital twin technology can help to understand maintenance needs and schedule maintenance as per requirement [8].

The digital twin gives real-time information for more informed decision making and the digital twin can even make predictions about how the asset will evolve or how the asset will behave in the future [14].

There has been tremendous growth in Digital Twin technology. Digital twin has many applications. Some applications will be discussed in this chapter. There are different possible applications of Digital Twin technology in various fields like manufacturing industries, smart cities, intelligent healthcare, etc. [2, 3].

The application of digital twins provides value creation within the fields of operations and service management [23]. The increasing utilization of information and communication technology allows digital engineering of products and production processes [16].

In the very recent years, the digital twin in industry has attained a relevant attention not just from researchers but also from practitioners as well [25].

Digital twin is also attaining very large interest from manufacturers that make products that are advanced and have complex systems all characteristics [26].

Digital twins promise great benefits for their different stakeholders when they are used to support the design, to support the manufacturing management, to support monitoring and control as well as optimisation of manufactured products, and the production equipment and systems in manufacturing [24].

Digital twin for a production process can be useful. The digital twin for a production process enables a coupling of the production system with its digital equivalent as a base for an optimization with a minimized delay between the time of the data acquisition and the creation of the digital twin [12].

The information provided by a digital twin can offer various optimization possibilities for a cyber-physical system [7]. A concept for the realization of the digital twin contribution to the development of a cyber-physical production system (CPPS) in small and medium-sized enterprises (SME) is presented [12].

From a simulation point of view the digital twin approach is the next wave in modeling, simulation and optimization technology [9]. The digital twin appears to be the most suitable source of knowledge within the smart factory from literature stated as per authors in paper [5]. Below discussed are different applications of Digital Twin.

7.3 Applications of Digital Twin

The digital twin technology is gaining importance due to its potential. Some of the applications areas of digital twin are smart cities, manufacturing sectors, healthcare, etc.

7.3.1 Smart Cities

The concept of smart cities is gaining importance. Smart cities are beneficial in different ways, hence they are gaining importance. Using digital twin for smart cities can be really very helpful. Employment of digital twin for smart cities application can help in different ways. It can help in planning related work of smart cities. Along with it, digital twin can help in development work of smart cities. Digital twin can also help the different departments of the city with its advantages, it can also help in monitoring the environmental parameters and changes, etc. So application of digital twin can be beneficial for smart cities.

7.3.2 Manufacturing Sector

By introducing digital twin in manufacturing sector, problems can be predicted before they come. If any problems are going to come in a product which is being made then corrections required in the product can be done before the final production of the product.

7.3.3 Healthcare

With digital twin, hospital management, patient healthcare, medical equipment manufacturing, etc. can be benefitted in the healthcare sector. Digital twin helps in avoiding problems, it also helps in smarter decision making, etc. which is useful in healthcare sector. Detailed discussion on the application of digital twin in healthcare is discussed in section 7.5.

7.3.4 Aviation

In the aviation field, digital twin can help with predictive maintenance. It can predict the requirement for structural maintenance and repair works. The structural life of the aircraft can be also predicted using digital twin.

7.3.5 The Disney Park

In 2019, Hitachi formed an alliance with Disney Parks, to work on data-driven solutions to increase operation efficiency and create great experiences for their guests who will visit Disney Parks. Their data-driven solutions include digital twin.

7.4 Challenges with Digital Twin

In each and every technology there are always some challenges faced. In digital twin technology also, there are some challenges. For example, some common challenges with digital twin are training requirement for working on digital twin technology and expenses of creating digital twin. Training and expertise would be needed to work properly and correctly. Digital twin cannot be just simply created and worked on without appropriate training and without having the much needed expertise. Also, there will be expenses involved in creating digital twin. From the software to the hardware requirements of digital twin will include its expenses. So these are some of the common challenges faced with digital twin.

7.5 Digital Twin in Healthcare

Healthcare sector is very vital. In healthcare sector, technology plays a very great role. Digital twin technology is having great importance in this sector. There are existing significant applications of digital twin in healthcare sector. Besides with the existing applications, there can be several more applications of digital twin in healthcare. On the basis of the literature survey carried out, discussed below are some applications of digital twin in healthcare which include existing real-world applications as well.

- Digital Twin for Hospital Workflow Management
- Digital Twin for a Healthcare Facility
- Digital Twin for Different Medical Product Manufacturing
- Cardiovascular Digital Twin
- Digital Twin Utilization for Supporting Personalized Treatment
- Digital Twin for Multiple Sclerosis (MS)

7.5.1 Digital Twin for Hospital Workflow Management

The workflow management of a hospital is very necessary. If there is no proper workflow management in a hospital then things will turn out to be very messed up. In each and every hospital there needs to be a proper work discipline which should be followed so that the workflow can be managed well. Hospital being a very highly important place, there are certain rules that every hospital has along their own particular schedule and work discipline which they follow strictly and especially when there are large number of patients visiting hospital, a proper disciplined workflow management becomes even more essential. Imagine the workload of hospitals during pandemic. The workload of hospitals during pandemic is skyrocketing. Even during regular non-pandemic times, hospitals always look forward for having a smooth and efficient workflow management. Despite the best efforts hospitals always put, sometimes the hospital workflow management work gets messed up in complex situations. Digital twin technology is best in such cases. It can very well help in smooth hospital workflow management. Consider the following example of usage of digital twin technology in Mater Private Hospital (MPH) in Dublin where this technology is employed for hospital workflow management. This is one of the real world application of digital twin in healthcare sector.

Mater Private Hospital (MPH) in Dublin, has included digital twin technology in their hospital. MPH engaged Siemens Healthineers Value Partners for Healthcare Consulting to optimize care delivery and create more value using a Digital Twin for Workflow Excellence. Hospital management of Mater Private Hospital felt an urge for having a change in their department of radiology. MPH were facing problems such as patient demand were growing, the infrastructure was becoming old, etc. All the problems were making it most difficult to provide productive patient care. Hence, they engaged Siemens Healthineers Value Partners for Healthcare Consulting. Digital twin for workflow excellence was used and the result was amazing. The hospital noticed the wait times were shorter for the patients thereafter for computed tomography (CT) scans and magnetic resonance imaging (MRI) and the turnaround time for patient for both CT scans as well as MRI was faster. The equipment utilization was more and there was yearly cost savings as well [20]. From this example, one can clearly notice that how well digital twin can help in healthcare sector's area of hospital workflow management.

7.5.2 Digital Twin for a Healthcare Facility

Healthcare facility like a hospital is always very carefully made but in a hospital there are so many things to look after and like all the arrangements, operational strategy, staffing, etc. Digital twin technology can be helpful. A digital twin of an entire hospital facility can be made. Digital twins can allow hospital to optimize resources and increase efficiency. Digital twins of hospital will help in analyzing the existing arrangements as well as in finding out if any improvements are required in the healthcare facility and testing and knowing the effects of different changes if made in the hospital. It can be extremely helpful and especially in times like pandemic where there are large number of patients visiting a hospital, this could help the hospital in various ways. By creating a digital twin of hospital, the management or staff can test different changes in operational strategy, capacities, staffing and also care delivery models so as to decide exactly which actions should be taken [21].

Thus as explained above, the digital twin for a healthcare facility can be very helpful in different ways.

GE's Hospital of Future Digital Twin

GE is working out on different new ways through which they can utilize simulation and prediction for improvement of hospital operations and patient care and in this context have come up with Hospital of Future

(HOF) digital twin. The HOF Simulation Suite has been designed especially for utilization in healthcare [21].

7.5.3 Digital Twin for Different Medical Product Manufacturing

Digital twin can help in healthcare largely. Medical products are of great importance. In healthcare various kinds of special medical products are used. Consider a medical product like vaccine. Manufacturing a medical product like vaccine requires great attention and care. Nothing should go wrong in the manufacturing process. To make sure everything goes well enough in manufacturing process, digital twin technology can be useful. Digital twin can be used for manufacturing process. It can then help in various ways like it can prevent wastage or decrease it, which is such a huge benefit. This will be very helpful. The process of manufacturing can be monitored remotely, which provides so much flexibility in work. This also will be very helpful. Similarly digital can help in more such ways when used for medical product manufacturing process.

7.5.4 Cardiovascular Digital Twin

A particular method for enabling cardiovascular digital twin by utilizing inverse analysis is suggested by [19]. The authors suggested a procedure for inverse analysis utilizing recurrent neural network for the cardiovascular system. To add to this, their procedure also suggested the use of virtual patient database which was generated, comprising of altogether 8516 patients and out of these, 4392 were abdominal aortic aneurysm (AAA) cases and 4137 were healthy cases. Through help of long short-term memory (LSTM) cells, blood pressure waveforms in different vessels of body are calculated inversely by inputting pressure waveforms from three non-invasively accessible blood vessels which are carotid, brachial arteries and femoral). Inverse analysis system which is built this way is applied to detection of AAA and its severity using neural networks [19]. On application of the proposed approach it was found that the suggested approach of inverse analysis makes development of an active digital twin, capable of continuously monitoring, and preventing medical conditions from developing or further aggravating feasible. When it comes to the case of cardiovascular system, this approach is potentially implementable in clinical environments and helps in monitoring cardiovascular parameters and critical vessels [19].

The method proposed by the authors work in [19] can perform inverse analysis with great accuracy. It found problems like AAA with high accuracy of 99.91% and classified its severity with acceptable accuracy of 97.79% [19].

7.5.5 Digital Twin Utilization for Supporting Personalized Treatment

Digital twin has the potential of being utilized to support personalized treatment of patients. There are certain cases where personalized treatment for patient can prove to be very useful. It can highly benefit the health of the patient. For example, consider the case of cancer. Here personalized treatment could be introduced with digital twin utilization for supporting personalized treatment. In this context, the authors [17] in their article, have used systems and mathematical modelling theory and on the basis of it, have put forward a classification of digital twins into different models. These different models are Grey Box model, Surrogate model and Black Box model. Then the authors explore one possible approach, namely a Black Box classification. This is for incorporating the usage of digital twins in the context of personalised uterine cancer care [17].

7.5.6 Digital Twin for Multiple Sclerosis (MS)

Authors in [18] discuss regarding the usage of digital twins for MS. They discuss about digital tool being used as a tool which can improve monitoring, diagnosis and therapy refining patients' well-being. This will save costs and allow to prevent progression of disease. Digital twins will help make care patient-centered and also make make precision medicine a reality in everyday life. According to the authors [18], with the digital twins development for Multiple Sclerosis (DTMS), it is possible to make the clinical decision-making for individual patients, shared decision-making, patient communication and thus ultimately quality of care better [18].

7.6 Digital Twin Challenges in Healthcare

There are different challenges that digital twin faces in healthcare. Some of them are as follows.

- Need of Training and Knowledge

- Cost Factor
- Trust Factor

7.6.1 Need of Training and Knowledge

During developing any medical product using digital twin or while using digital twin for any other application in healthcare, any mistake caused due to human error can have a serious negative effect.

Hence the working with digital twin and handling it requires training and knowledge. Everyone cannot work with it and handle it in a sensitive sector like healthcare. So training would be needed with detailed knowledge about it. This is also a challenge in general that digital twin faces as well as it a challenge in the healthcare applications as well to ensure that required training and knowledge is provided to the staff who will be working on digital twin.

7.6.2 Cost Factor

Creating and including digital twin in healthcare means additional increase in cost. The cost factor or expenses of creating a digital twin is also another challenge faced in general as well as in healthcare applications. As discussed above, there won't be just the cost of creating digital twin but also there will be also cost expenses in training the staff to work on digital twin and handle things related to it. So this a major challenge for digital twin.

7.6.3 Trust Factor

Every technology being introduced in healthcare which is a very important and sensitive area not only needs reliably amazing results from it but also needs trust of the people. When digital twin applications in healthcare include hospital management, help in development of medical instruments and devices, etc. the advantages of it come across as very useful and it becomes easier to trust this technology. However, when one talks of including digital twin to support personalized treatment and personalized medicine then here the trust factor could be a major challenge. Digital twins are having the ability to model individual patients with varying physiological traits and mechanistic differences. Therefore, digital twins are a natural, complementary strategy to implement personalized medicine [22]. However, it might not be easily trusted by everyone. It requires time and evidence for people to trust a technology in the case of healthcare.

At present digital twin is evolving and it is yet to be fully introduced and utilized at a large scale in healthcare sector but again here the large scale introduction and utilization of digital twin in healthcare does not guarantee that the people will trust it, especially in the case of implementing personalized medicine. Also, the data security and data privacy risk will also again come into picture here. This will further increase the issue of the trust factor. Due to this, people will find it more difficult to trust this technology in healthcare. So the trust factor is great challenge for digital twin in healthcare applications.

7.7 Conclusion

With inclusion of different technologies there have been great innovation, developments and advancements in healthcare. Along with so many advancements, introduction of digital twin and its application in healthcare can be very beneficial for this sector.

The main contributions of the chapter are as follows,

- It discusses about what is digital twin.
- The current application of digital twin not only on healthcare but also on different fields has also been discussed.
- The main focus of this chapter has been to discuss and emphasize the applications and importance of digital twin in healthcare. By utilizing digital twin, the healthcare sector can be benefitted as seen in this chapter. The chapter also explains the digital twin challenges in healthcare.

The applications of digital twin for healthcare discussed, explained and emphasized in this chapter are digital twin for hospital workflow management, digital twin for a hospital facility, digital twin for different medical product, digital twin for enabling a cardiovascular digital twin, digital twin utilization for supporting personalized treatment. And digital twin for multiple sclerosis All these applications clearly show the importance of digital twin in healthcare sector and the kind of difference its presence and utilization can make in this sector, like we saw in the case of Mater Hospital for example in Dublin.

The benefit it received from digital twin application or utilization was great. The presence of digital twin caused a great difference here. This hospital's problem of workflow management was solved efficiently with digital twin.

Likewise, in other digital twin healthcare applications also explained in the chapter, we saw that digital twin presence and utilization made such a huge difference.

The effects and results of using digital twin in different healthcare applications seen in this chapter were very phenomenal. Digital twin is yet not largely introduced and yet not implemented on large scale in healthcare sector but with digital twin showcasing great results and effects and promising of benefitting the healthcare sector its presence and application in this sector might grow further quickly.

However, there are some challenges as well which digital twin faces in this sector of healthcare which are all also discussed and explained in this chapter. Solutions need to be found and implemented for the challenges so that they can be overcome which will benefit ultimately the healthcare sector largely as it will open doors to the pathway leading to easier large scale implementation of digital twin in healthcare sector. Though digital twin has been evolving but there are still so many things related to digital twin that need to be explored in context with the healthcare sector. Therefore, the future insight of digital twin especially in healthcare is considered to be a vast area to explore.

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