Smart Healthcare System: Automated Methods for diagnosis of diseases using Digital Twin Technology

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ABSTRACT

Digital twin technology, which is build on real-time data integration, robust diagnostics, and virtual simulations, is significantly interchanging the healthcare industry. It is the process of manufacturing virtual replica of an actual object, platform, or technique. This digital representation enables real-time shaping, analysis, and monitoring. Digital twins offer enhanced diagnostics, preventative maintenance, and optimization by recreating the real-world entity. By merging data from many sources, including the Internet of Things (IoT), this innovation produces virtual replicas of patients and offers individualized therapy based on real-time physiological data, patient characteristics, and medical histories. By fusing AI and machine learning algorithms, digital twins offer predictive analytics, setting the bar for early health problem diagnosis and preventative treatments. These virtual simulations have also demonstrated their value in streamlining administrative procedures, enhancing patient care, and providing immersive learning environments for medical professionals. Additionally, with the spread of pandemics like COVID-19, technology has become increasingly important for remote health monitoring, proving its efficiency in protecting medical staff and delivering appropriate patient care. Its potential is increased even further by incorporating additional cutting-edge technologies, including blockchain, deep learning algorithms, along with the Internet of Robotic Things (IoT), especially in the domain of predicting several diseases, treatment accuracy, and data security. The development of immersive patient care encounters in the metaverse has also been made possible by digital twins. The need for active initiatives to increase utilization is necessitated by the persistence of issues with data interoperability, quality, and security. Digital twin technology promises to usher in a new era of precision medicine, individualised therapy, and a data-driven approach to patient care as it is further integrated into the healthcare industry.

Keywords: CNN, IOT, DEEP LEARNING, MAMMOGRAMS, REMOTE MONITORING, NLP

1 INTRODUCTION

The Digital Twin stands out in the rich tapestry of recent technological developments as a beautiful thread that threads its way from the immensity of space exploration to the delicate minutiae of medical care.

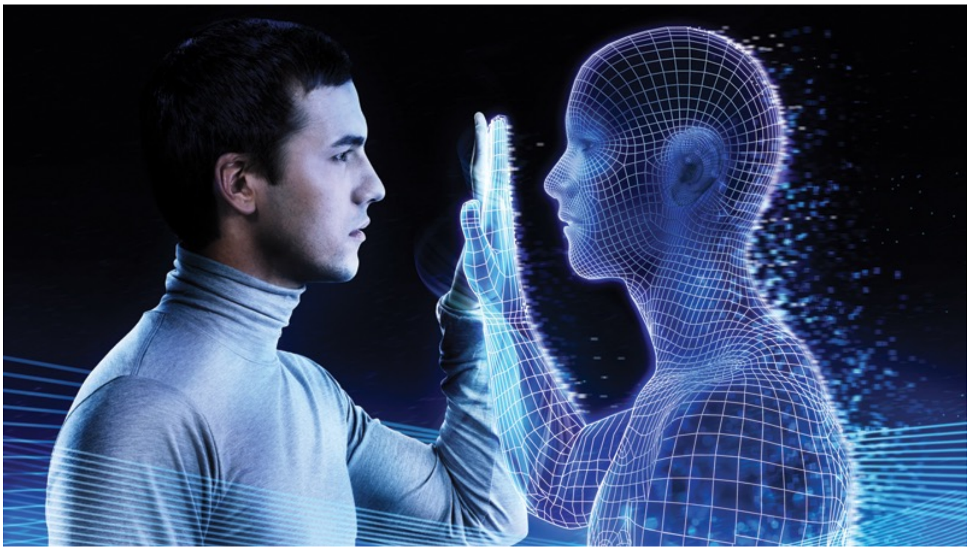

Figure 1: Digital twin corresponds to a computer-generated representation of an actual real world object, person or procedure which is capable enough of replicating their behaviour and has the capacity to learn about their operations.

The concept was created in the 1960s, and its pioneering uses may be traced to NASA's bold space missions, particularly the legendary Apollo operations. However, what was once a ground-breaking project by industry titans in the aerospace industry has now found favour across a wide spectrum of businesses, altering the way in which they conduct business and opening up new horizons of opportunity.

The idea of a "Digital Twin" was created to demonstrate human ingenuity and adaptability. It's a tale that begins with NASA's guidance, receives formal recognition as a result of philosophers like Michael Grieves' works, and through definitional changes when other industries discover new applications for it. In addition to revolutionising aviation, the technology also contributed to laying the foundation for Industry 4.0, sometimes known as the Fourth Industrial Revolution. Real-time data mirroring and a bi-directional link allowed for this. [1] But it's probable that the digital twin idea has had the biggest influence on the medical industry.
The technology imagines a time when all facets of healthcare—from conception through end-of-life care—are improved, tailored, and optimised. In a nation with major health problems, most notably the COVID-19 epidemic, the employment of digital twins in healthcare represents both technological innovation and optimism. This integration offers a healthcare vision that extends beyond predetermined boundaries, leading to the creation of a system that is more responsive, flexible, and personalised.

We'll go back in time as we read the rest of this chapter to look into the beginnings, development and utilizations of digital twins. By the end of the presentation, we want to have fully explained how this idea, which started out as a tool for space exploration, is now essential for

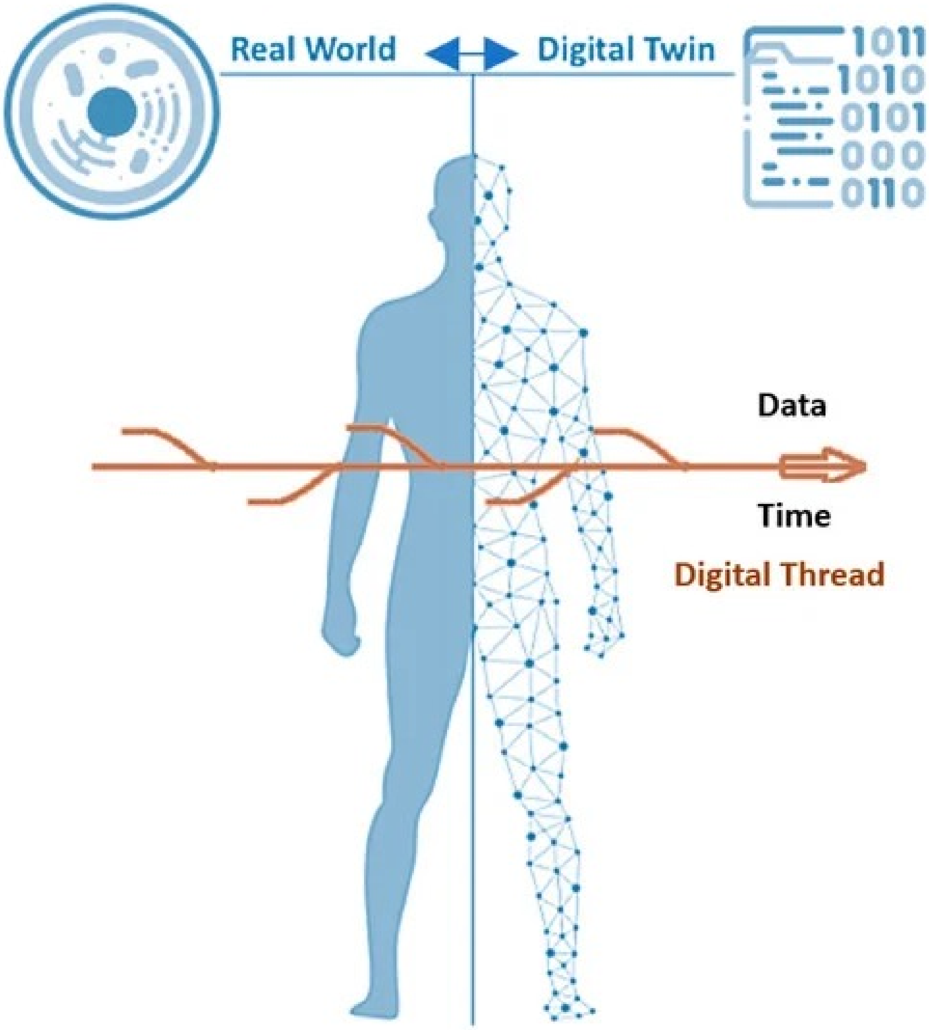

Figure 2: A virtual model of any actual physical object is called a digital twin.

personalising medical care and has the potential to completely change the way healthcare is delivered in the future.

2 BACKGROUND

Digital Twin's origin traces back to the late 1960s. The phrase "Digital Twin" has developed and gained significance through time, popping up in a number of industries, most notably aerospace, manufacturing, and product lifecycle management. From the existence to the development of a Digital Twin, it has been discussed in detail here.

The first time NASA utilised Digital Twin to model and plan space missions was in the 1960s, which is where the technology's origins may be found. This was especially crucial in relation to the Apollo missions. For the first time, digital simulations were employed to model how individuals would act and function in the real world.

"Digital Twin", the term itself was first mentioned in a presentation by Michael Grieves in 2003. It's critical to keep in mind that the idea predated the invention of the term. [3] Grieves

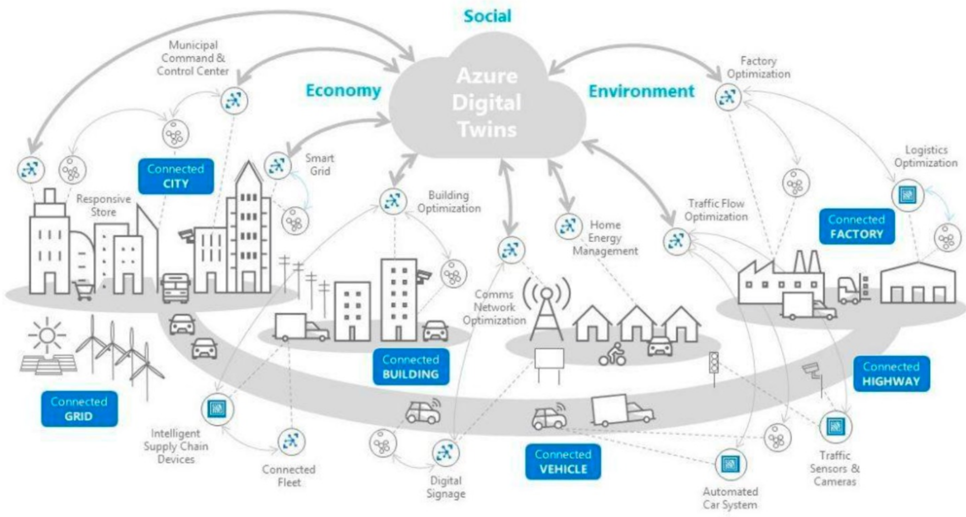

Figure 3: Twins connected through the Azure Digital Twin Ecosystem [2] create a Real-World Environment.Each twin is unique in ways that impact their ability to connect to a complex knowledge graph.

played a very substantial role in the development and popularization of the concept of digital twins. IGlaessgen and Stargel defined this technology for the very first time in 2012, goes as a ”multi scaled statistical simulation of a formed vehicle or any other complete system which uses the most appropriate models and sensors, fleet history etc., to reflect similarly the life of the corresponding twin.” Because of this concept, the aviation industry was able to broadly adopt the technology of the Digital Twin.

Digital Twin’s definition has changed as its uses have gone beyond those of cars and airplanes. A digital twin, according to Grieves, consists of three elements: the real item, its virtual replica, and the connections that allow two-way communication between them. With the help of this two-way data flow, which also an essential element of the technology, it is now possible to do real-time monitoring, system performance analysis, and predictive modelling.

Thanks to the efforts of scholars and practitioners, the Digital Twin concept has achieved significant progress. Tao et al.’s five-dimensional models of DT expanded on the underlying three-dimensional architecture with the addition of digital twin data and services. This change enabled the combination of data from the physical product and its digital equivalent, as well as the provision of service components to improve functioning.

Digital twin technologies have become more popular as a result of the digital revolution, rapid advancements in several industries like the Data, Cloud Computing, IoT and distributed systems etc. The deployment of Digital Twins across a variety of businesses was made possible by these technological developments, which produced a favourable environment. The Fourth Industrial Revolution’s crucial element of the Digital Twin is now recognized as having the potential to modernize industries and boost productivity. Additional Recognition and Formalization: David Gelernter’s 1991 book ”Mirror Worlds” recognized digital twins, and Michael Grieves formally proposed them as the conceptual paradigm for product lifecycle management

(PLM) in 2002 [4] . The phrase ”Digital Twin” was invented by John Vickers of NASA in a Roadmap Report from 2010.

An very precise copy of a system that might reproduce the original system is termed as digital twin by the International Council of Systems Engineers (INCOSE). A DT can be considered as an integration of probabilistic multi-scalable simulation, enabled by Digital threads, which replicates and predicts actions and performance of its physical counterpart across time, according to the United States Department of Defense’s evolving Digital Engineering Strategy. This idea is consistent with that strategy.

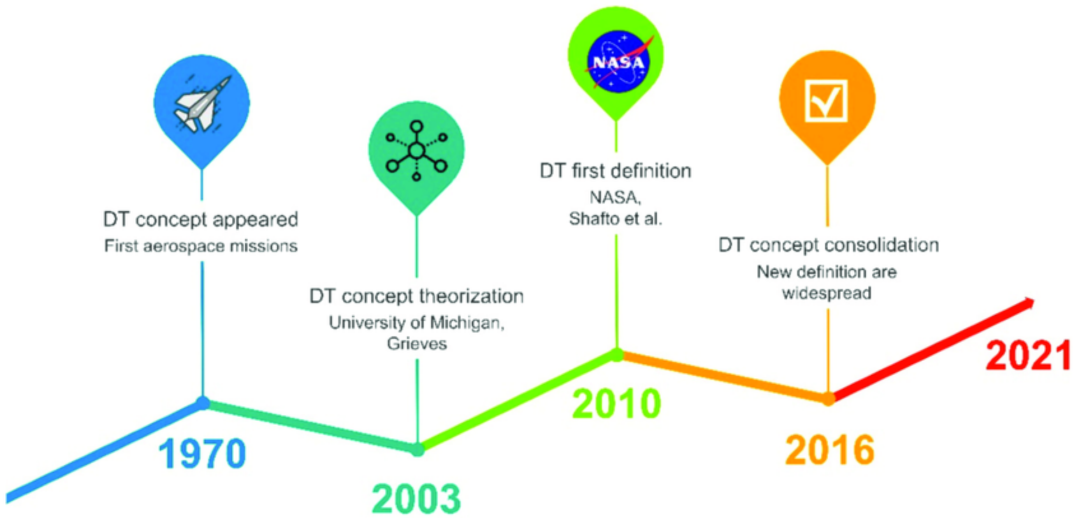

Figure 4: The above image depicts the evolution of the Digital Twin concept over time, from its early applications in NASA space missions to its current prominence as a cornerstone of Industry 4.0. It has made incredible progress as a consequence of the efforts of numerous professions and technical advances, and it is now an essential component of modern engineering and industry. This method establishes the foundation for a concrete literature review about the uses of this digital twin technologies across various industries. [5]

3 MAIN FOCUS OF THE CHAPTER

The primary outcome of the digital twin is to enable virtual tool designing, testing, and its construction. This technology is used in healthcare to enhance pre-operative planning, reduce medical risks, and provide patients with more precise treatment. To uncover inefficiencies and create changes, such as lowering patient wait times and creating plans for making the most of diagnostic testing equipment, it may be used in medical institutions to model workflow procedures. Using AI, Deep Learning, and IOT, the primary goal is to integrate a device’s or patient’s digital twin into healthcare facilities. It will show us the patient’s or device’s precise real-time status.

The crucial issue of exam postponements, disturbances to patient and hospital operations is addressed by the digital twin idea. It permits unscheduled downtime, expensive downtime, and patient pain, all of which might have an effect on therapeutic outcomes. The digital twin enables quicker tests that would have required months or several iterations to develop physical prototypes by performing simulations on virtual prototypes.

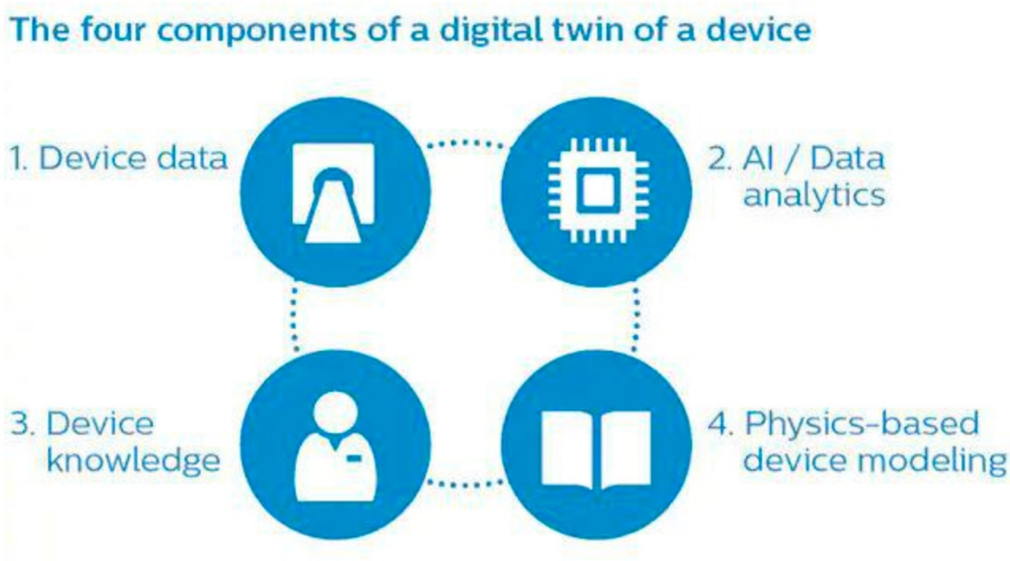

Figure 5: Digital Twin and it's components: A gadget's digital twin is represented by the four main components in the image above. This method has extensive use in the healthcare industry, where hospitals may be digitally simulated to assess staff and systems, ultimately leading to better operations. For patients, Digital Twin technology also has the capacity to produce exact replicas of certain organs, like the heart, or even single cells. This advancement makes it feasible to perform simulations to determine how certain patients might respond to various treatments.[6] This trend represents a radical departure from conventional, broad-based research and a drive towards completely personalised medical care. These models may be created quickly and inexpensively, offering real-time guidance for selecting a course of diagnosis and treatment

A digital twin can also assist in choosing the best course of treatment for a particular patient. Surgery, radiation therapy, and less invasive treatments such as hormone therapy are all alternatives for treating prostate cancer.[7] These drugs can be used with different subgroups, which adds to the complication. A model of the prostate cancer clinical route and a digital twin that incorporates a patient's genetic information, lab findings, and imaging data work together to guarantee that the optimal therapy options are chosen for that specific patient. Consider a specific real-world healthcare scenario that follows the clinical workflow illustrated in Figure 7.

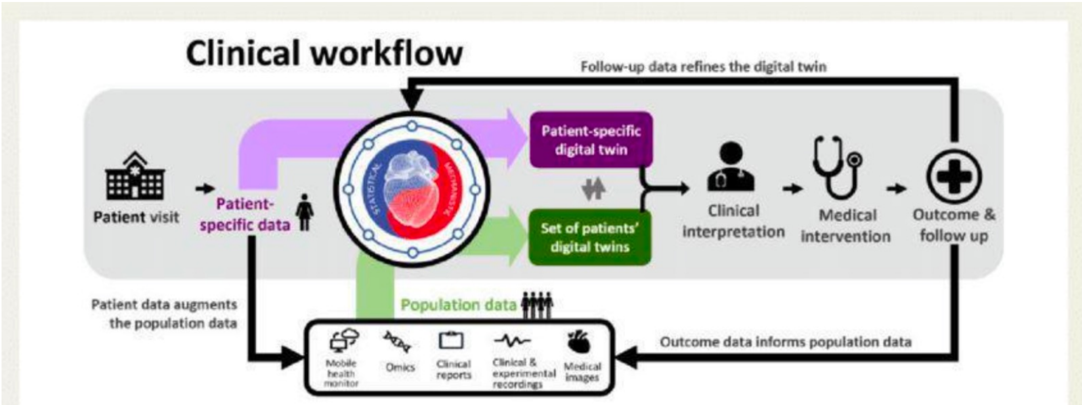

Figure 6: Clinical Workflow of Digital Twin

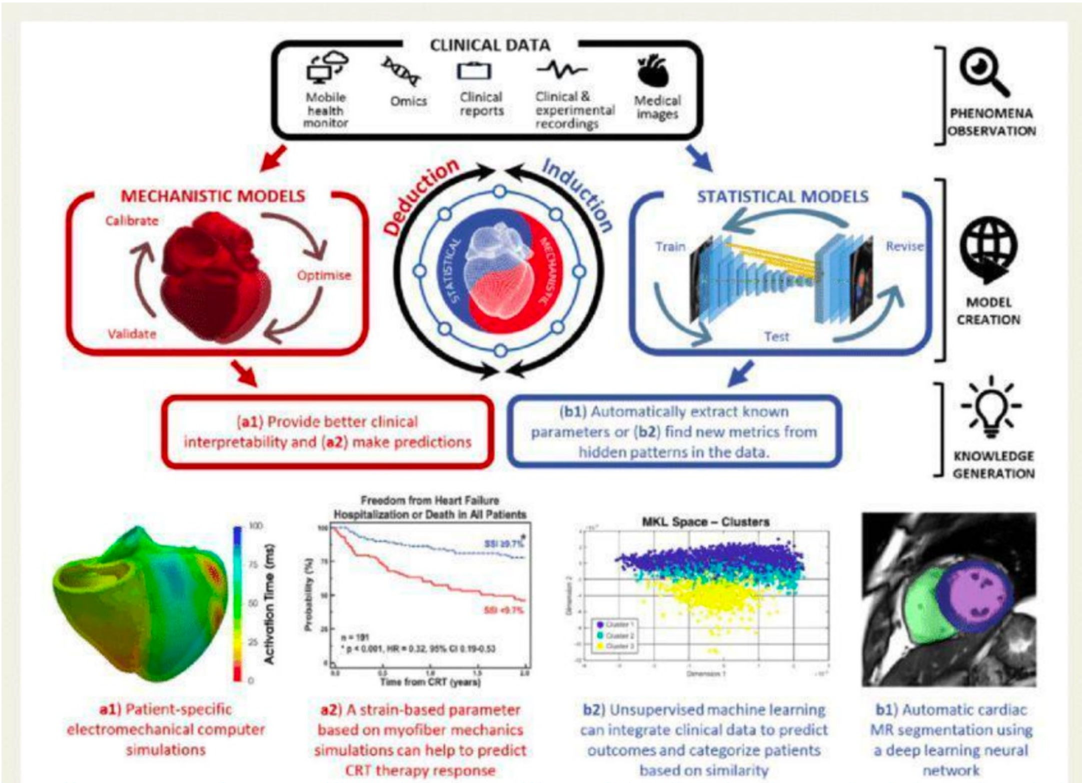

Figure 7: Executioin of the Flow (The digital twin's two pillars, mechanistic and statistical models, as well as four application examples [8])

3.1 STEP TO STEP EXECUTION OF WORKFLOW

PATIENT:- Mid-aged women suffering from breast cancer provide data to Digital Twin Healthcare System.

3.2 CLINICAL DATA

TEST RESULT

S.No.	Test	Interpretation	Intensity	% Tumor Staining
1.	Estrogen Receptor	Positive	2-3+	90
2.	Progesterone Receptor	Positive	2-3+	100
3.	HER-2/Neu HercepTest	Negative	1+	40

Figure 8: Test Table for the Clinical Data

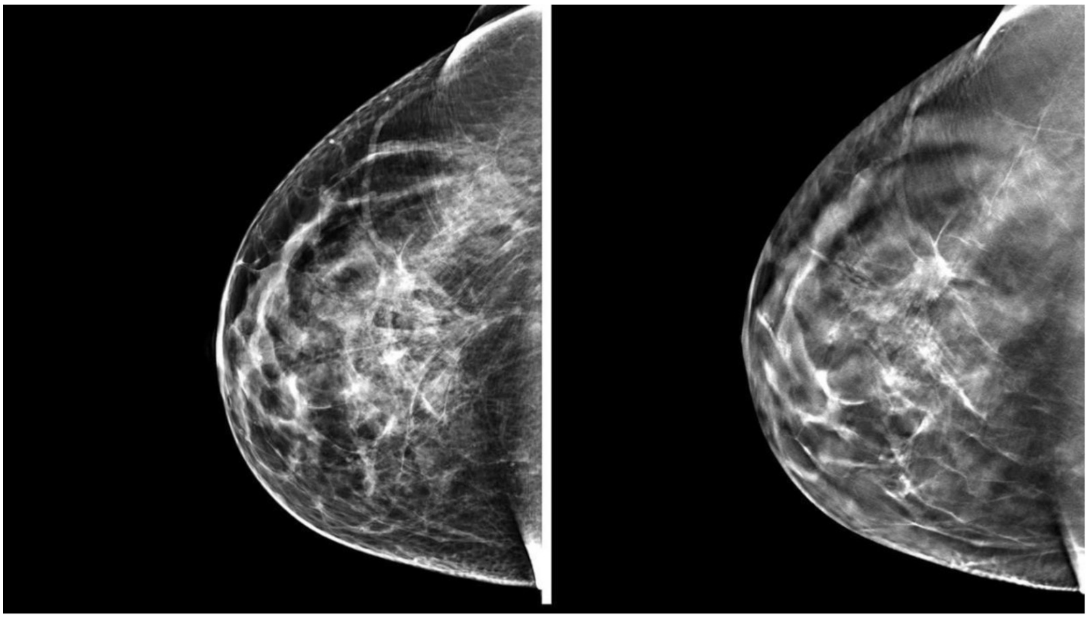

Figure 9: Virutal Image of a Mammogram in Digital Twin

3.3 Healthcare using Digital Twin Model: Five Dimensions

Healthcare has adopted using digital twin technology, a tenet of Industry 4.0 in manufacturing. Applying the five-dimensional Digital Twin concept to healthcare becomes a quite challenging venture due to special challenges and complexity involved in dealing with people and their health. Every step of the healthcare process entails ethical, statutory, privacy, and security issues and calls for domain expertise. Despite these difficulties, interest in Digital Twins for Healthcare has increased, especially since the COVID-19 outbreak. [9]

3.3.1 Supporting Healthcare at Different Life Stages with a Digital Twin:

Patients are the physically existent entity in a proposed digital twin system for healthcare. The three key stages of healthcare that are covered by this paradigm are preconception care, lifetime care, and afterlife care. Product lifecycle management served as its driving force.

3.3.2 Preconception Care:

Proper preconception care is critical for lowering the risk of maternal and infant mortality and encouraging healthier pregnancies. Digital twins in preconception care use health information technology, such as virtual patient advocates and mHealth smart pregnancy programmes, to deliver tailored preconception care information and coaching. Early pregnancy and IVF vision can be enhanced with the use of virtual reality and developments in ultrasound technology. Digital twins might be utilised in genomic projects to help with genetic research, diagnostics, early therapies, and long-term genomic data.

3.3.3 Lifetime Healthcare:

Numerous techniques, including customised precision medicine and therapy and multimedia platforms for the exchange of health information, utilise advanced information technology in lifelong healthcare. Through simulations, virtual patients, virtual reality learning platforms, and other technology breakthroughs, education, knowledge sharing, and personalised healthcare information are made feasible. Athletic training, real-time health monitoring, and enhanced patient care in intensive care units are all made feasible by digital twining. By helping to identify risk factors or early warning indications in health indicators, it facilitates better clinical diagnosis and decision-making. Less invasive surgery, remote surgery, databases for specialised treatments, surgical simulation, and less invasive surgery are further ways that DT is used to improve surgical planning and training. To improve management and operational effectiveness.

3.3.4 Afterlife Stage:

Digital twin technology can improve decision matrices, mimic organ transplantation, and streamline the logistics of transporting organs. However, there hasn't been much public interest or study focused on the post-mortem phase of healthcare. It also raises questions regarding the longevity of digital data and the digital traces that have been left in the medical field.

3.3.5 Everything can be Digitally Twinned as a Healthcare Service:

"Digital Twinning Everything as a Healthcare Service" is the concept's name. This paradigm classifies tools, patients, and facilities in addition to other physical elements, highlighting the multiple levels of physical integration in healthcare. Medical devices, smart healthcare devices, and wearable fitness or health monitoring equipment are examples of gadgets, although they are not the only ones.Patients find it difficult to make moral choices because of the complexity of human physiology, yet advances in the digitization of DNA and cell data are being made. Facilities include things like hospitals, healthcare institutions, surgery, healthcare services, and healthcare professionals. [10]

These physical parallels' digital counterparts provide a comprehensive platform for improved healthcare services. Monitoring, diagnosis, and precision treatment all benefit from increased information exchange, research innovation, healthcare resource management, and healthcare education. Integrating Digital Twins into healthcare services has the power of improving healthcare all around the world in a quickly changing and increasingly digital environment.

In order to improve healthcare outcomes as well as services for people at different stages of development, the use of digital twins in healthcare requires digitizing physical objects. This new paradigm has the ability to address specific problems and moral conundrums while also revolutionizing how education, research, and healthcare are provided.

4 MECHANICAL MODELS

Primarily used:- Gompertz,Bertalanffy and logistic models The mechanical model provides better clinical interpretability and also makes rough predictions. It takes the report and test results as input and provides a required interpretable solution in form of numbers and also does prediction of disease. Though, due to Advanced Deep Learning and Computer Vision techniques they are getting less used now. [11]

4.1 STATISTICAL MODELS:-

Machine Learning Models Primarily used- SVM, XgBoost, Logistic Regression They are used on features extracted by deep learning models or on the test data to predict or give the possibility of disease or to predict probability of getting cured. Deep Learning Models Primarily used here:- Xception (CNN),RNN,MLP. [12]

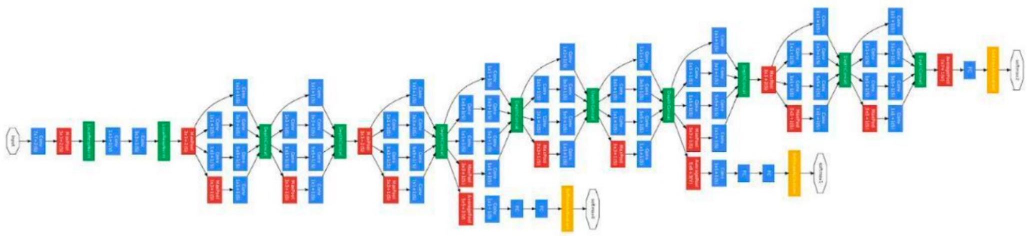

Figure 10: Feature Extraction Exception Layer

We have taken exception to extract feature vectors for the mammogram images that help us to predict:- 1 Probability of disease 2 Probability of getting cured 3 Possible requirements in Data Other uses of Deep Learning Models Here:

- Encoder Decoder model will provide summary of disease and reports
- Adversarial Networks will give better clear and operative image
- Extract unknown parameters and weights of required factors
- Find pattern and relation in Our Data

4.2 THE NON SEPARABLE INTEGRATION OF AI IN THIS ARCHITECTURE AND SYSTEM

1. AI Chatbots will take all the information from the patient
2. Latest Encoder Decoder and **BERT** based Natural Language Processing models will prepare report and communication platforms for the patient and healthcare system.

3. Machine Learning algorithms will predict and detect possible phenomena,symptoms and also prescribe tests based on that to the patient.

4. Test data and results will be made more relevant with help of feature extraction by **MLP** and also the weight and parameter for every symptom and factor will be evaluated.

5. The Adversarial Networks like **GAN** will be used to obtain more relevant scans and images for further detection.

6. Deep learning algorithms will be used in treatment as described above

7. Unsupervised machine learning algorithms like **Clustering (k-Means,DBSCAN)** will be used to categorize symptoms and workflow.

8. On the basis of caption generation technique ,medical reports will be generated using **CNN-Encoder** and **RNN-decoder** methods with attention mechanisms.

4.3 THE INTEGRATION OF IOT

1. Storing data from sensors and scanners in software with the commands.

2. Connection of AI chatbots and programs with IOT devices to execute according to instructions.

3. Connecting hardware devices in clinical applications using IOT.

4. Evaluating real-time reports, scans and graphs in physical form using IOT.

5 ANALYSIS OF DIGITAL TWIN IN MEDICINE

Only 22 of the 465 papers we located throughout our search met the inclusion criteria; hence, all of them were included in the analysis that followed. The flowchart for the selection process is shown in Figure 12. Although they were included in this study, articles that just addressed models or did not provide applications were deleted during the eligibility screening and data extraction. The popularity of Digital Twin research in medicine is rising on a global level. 2010 saw a large increase.

According to a distribution analysis, the countries with the biggest percentages of papers published in medical DT publications are USA[13] (35%), China (11%), and UK with (15%). Among other countries, other with significant participants are Australia (7%), Italy (6%), Canada (5%), Japan (5%) and Korea (4%).

6 ISSUES, CONTROVERSIES, PROBLEMS

It is seen with the fictional eye that AI might someday replace every major industry and with every day passing it is becoming more and more realistic but with the sole exception of the healthcare industry. With the faster spread of technology, the attention paid to security becomes less at the outset. This condition forces companies globally to scramble to put out emblematic fires when the vulnerabilities are being over-exploited, leading to a loss of both time and profits. The large and massive amounts of important data being collected, processed and utilized

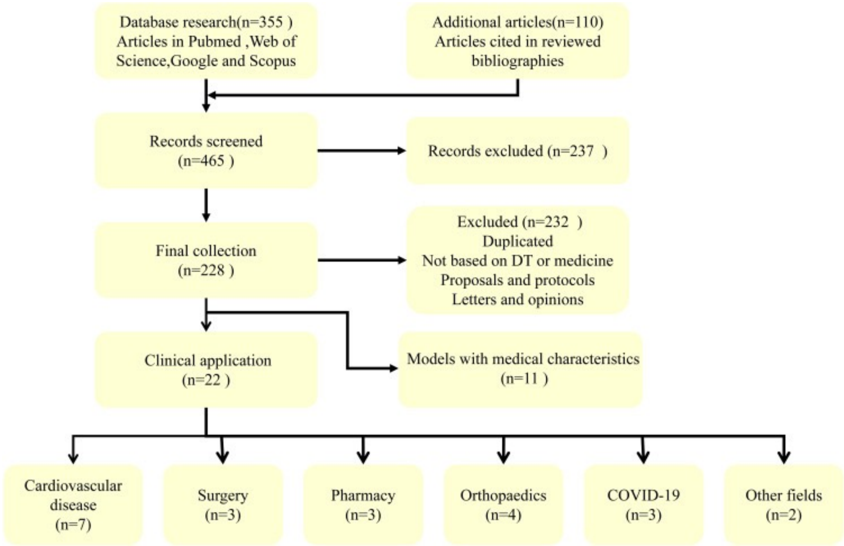

Figure 11: The study provides a flow diagram that illustrates the screening process for papers.

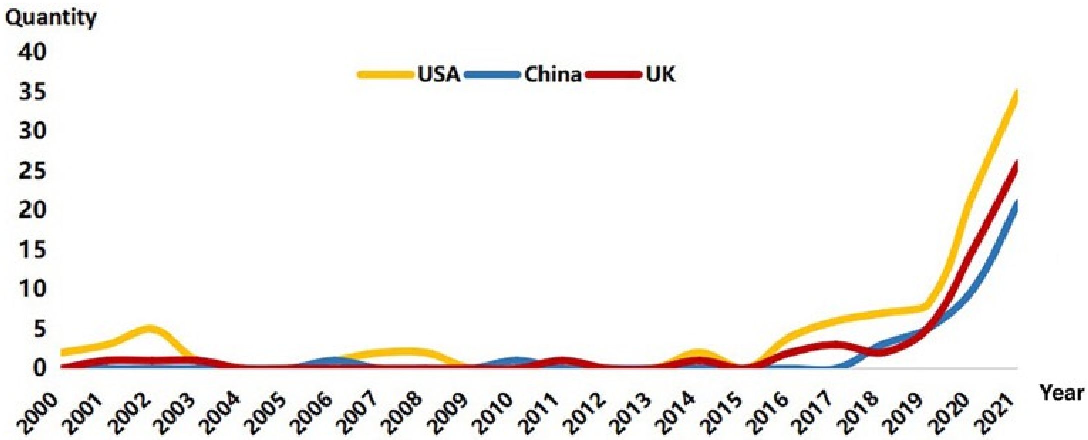

Figure 12: A comparison of experiments on digital twin technologies from the past 20 years was carried out in China, USA and the UK. Recently in the USA, researchers successfully performed the first digital twin test for a simulated microreactor at Idaho National Laboratory.

are being drawn from a large number of numerous endpoints, where each represents the potential areas of weaknesses. It is estimated that 75 per cent of the digital twins will have to be integrated with a minimum of five endpoints up to 2023, and the time is coming when we will require the linking of multiple digital twins to visualize complex systems. As data flows between devices and the cloud increase, potential compromise risks increase. Businesses considering digital twins should be cautious not to rush into adoption without checking, updating, and assessing current security protocols, with areas of greatest importance being:

1. Data Encryption
2. Accessing privileges, including a clear definition and understanding of user roles
3. The principles of least privileges
4. The known device insecurity vulnerabilities must be assessed

5. The security audits should be done on a routine

The very steep power of computing stands in need of running the imitation of the extensive human body organs can be dangerous. Let's take an example of the Blue Brain Project, the modelling of individual neurons can lead to 20,000 ordinary or high-level differential equations in the process. For the entire regions of the brain, we will have to solve 100 billion differential equations concurrently.

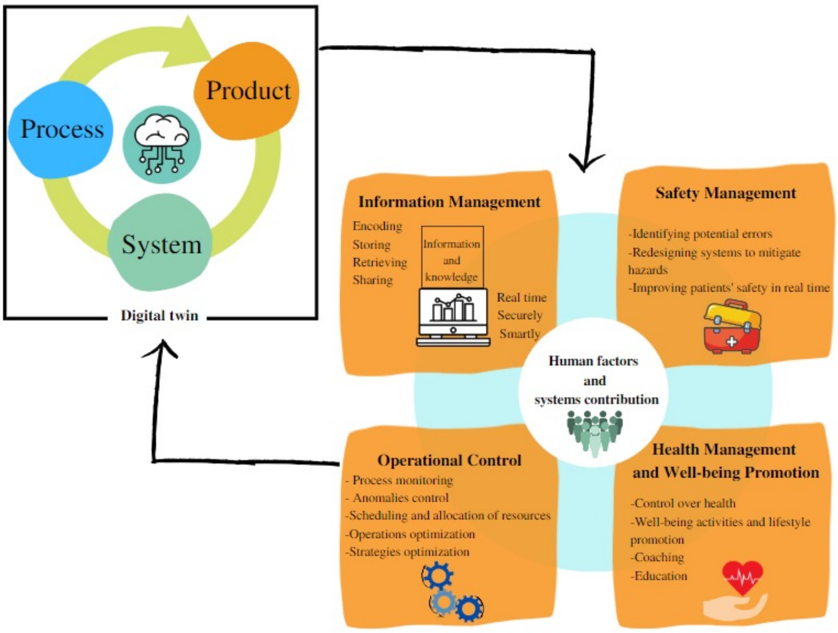

Figure 13: A model for categorising digital twin's impact from the perspectives based on human factors and systems.[14]

7 SOLUTIONS AND RECOMMENDATIONS

Fictionally, it seems quite possible that one day it might happen that human physicians might get replaced by Artificial Intelligence. But evidently it is observed that it is not going to be a feasible reality in the coming future. At the same time we can not overshadow the possibility of the assistance that Artificial Intelligence may provide to the healthcare industry to make decisions that are completely void of human errors and might even prove effective in reducing the load of every single patient on doctors. Along with that, lifting the burden of large amounts of information on healthcare records and framework administration for healthcare organizations with a purpose of significant decrease in deployment and end costs.[15]

Even though data count will be too high and storage issues may be prevalent, security of the data and protection will become better in this technology. The virtualization of the healthcare environment and digital access to data and information will have a better impact. Global tech-giants and collaborative startups have started researching solutions for the challenges in this domain.

Figure 14: Digital Twin Model of a Human Heart: The image shown is not an actual heart but rather a copy which is pounding inside the patient's chest. The digital twin—a fully functional simulation of human anatomy— pumps at a leisurely pace as it helps in testing other possible treatments along with other drugs and implants. [16]

As part of their study to improve the production of digital twins, the FDA recently agreed to a five-year partnership with Dassault in addition to partnering with startups such as 3D EXPERIENCE Lab, SOLIDWORKS, EEL En- ergy, Leka, L'increvable, Perseus Mirrors, SYOS, XSun, and XYT.

In 2017, Forbes suggested regarding digital twin technology that using this technology could lead to improvement in the speed of the critical processes by a difference of 30 percent. According to Gartner, The companies involved in industry could see a large improvement of 10 percent in effectiveness.

The Department for Digital, Culture, Media, and Sports (DCMS) 5G workroom and Trials program provided £3.5 million to the Liverpool 5G Health and Social Care laboratory. The workshop's aim is to find out whether widely accessible 5G connectivity benefits those without technology access by providing them with dependable access to digital health and social care solutions.

8 FUTURE RESEARCH DIRECTIONS

The Artificial Intelligence system is initiated after an initial training with the previously collected and compiled data. After the successful initiation it becomes really necessary for data supply to be continuous for further advancement and building of the system. Major drawback is that the current healthcare environment is not incentivized in the direction of data sharing.[17]

Artificial intelligence technologies always attract fascination and huge attention in the fields of healthcare research, however there are several obstacles in their real-life applications. First of which is the regulations. It is evident from the lack of standards of current regulations for protection and potency of Artificial intelligence systems.

Taking advantage of Huge data with vast knowledge, AI(Artificial Intelligence) is expected to collaborate with the most challenging but very near study of real-life questions, which leads to better decision-making in the management of health hazard. Presently, researchers have begun

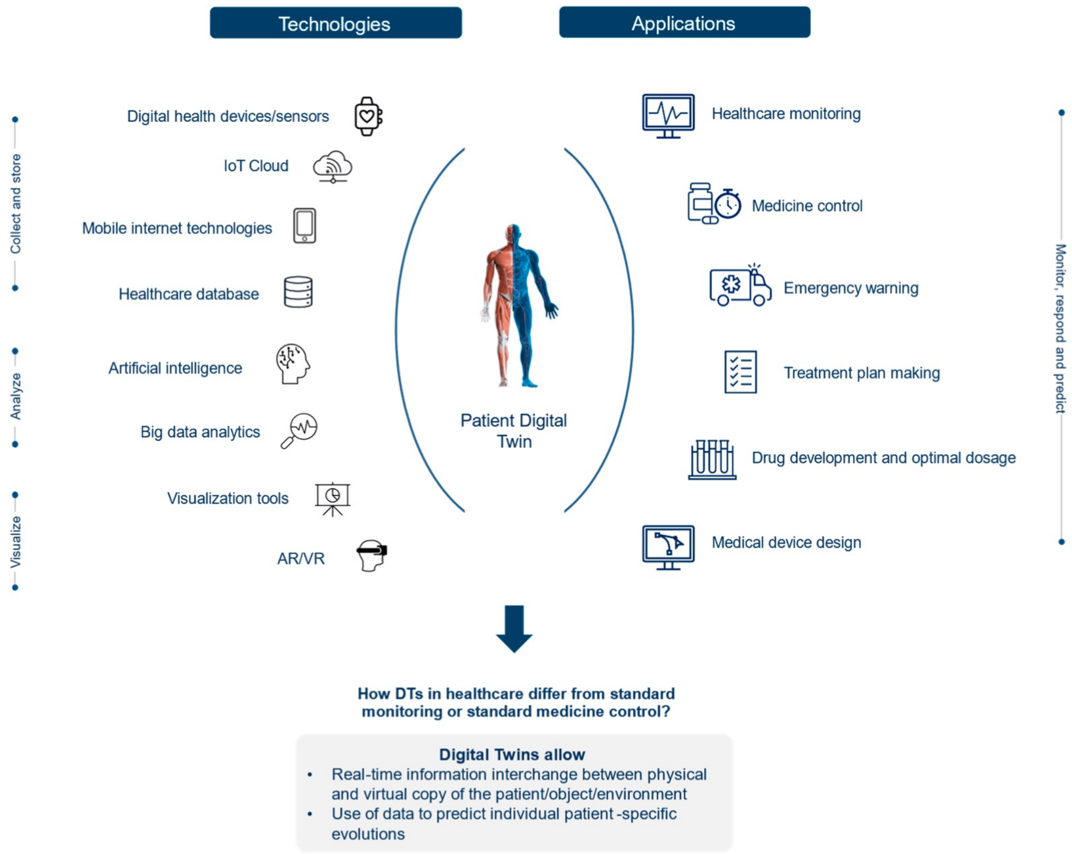

Figure 15: Overview of Some Important Architectures used in DT: DT Technology has the potential to revolutionize other industries, in particular manifacturing and healthcare sectors since inventions made here will be tremendously useful. [18]

experimenting with this direction and have found the preliminary results to be promising.

Technology such as portable internet, cloud computing, and the Internet of Things are currently actively handed down in the healthcare industry. The majority of studies, however, focuses on data monitoring and platform emphasis, with only a small amount of studies published in real-time disaster warning or counselling. Digital twins represent a viable answer to the problem of information-physical linkage and communication. Digital twins, when applied in the health-care field, can provide consistent support for cloud healthcare services. This will help medical institute administrators to improve their internal processes as well as their physical architecture. The combination of these discoveries into 3D projections of the human body organs will be the next pivotal and new step in the areas of personalized medicine and sciences. Wearable sensors like the Bio-Sticker, which can transmit real-time data to a computer which is very far away, allowing your digital duplicate to thrive. [19]

Using this technology, your doctor as well as you will be notified on a regular basis when specific tests and procedures are required for taking preventive measures. We would be able to predict which patients would become ill weeks or months in advance,how a particular patient would react to a given medication, and which patients would profit the most from treatment. This has the potential to change the way medicine is practised.

As a result, DT research and advancements in IoT, big data, and AI technologies, more study will be done on the use of DTs in the field of healthcare. The healthcare worldwide, IoT spending will increase by 21.0% from 2012 to reach 188.2 billion dollars by the year 2025, while national health spending will be elevated by 1.50% to 1795 dollars per individual. In making medicines with accuracy, the DT can be very helpful, although this would ask integration and analysis of tremendous of data. [20]

Internet of Things gives technological aid for total awareness of physical products by utilizing several technologies based on data collection like 2D codes, and data capturing cards along with some sensors. For operations management and model development, a timely data collection along with recommendation based on the data which is already processed via communication technologies are crucial.

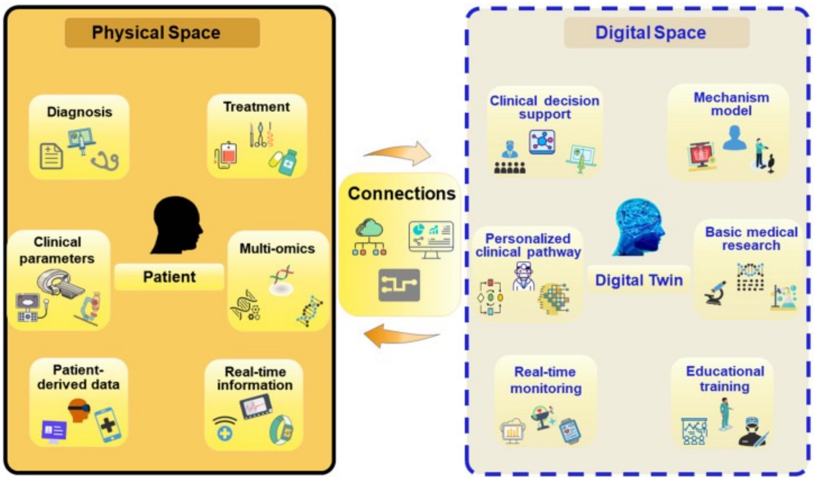

Figure 16: This is a table created for clinical data testing. It illustrates the use of DTs in medicine and makes assumptions about possible future uses. [21]

Everyone is required to have a DT. A cutting-edge platform and an experimental self-care strategy will be created by fusing the the digital twins of both the medical appliances and its auxiliary parts. For simulations using DTs with big data processing to provide precise therapy targets and proper medications or accurate methods of treatments for patients, high-resolution patient models can be used. Medical procedures motivated by patient demand are also made possible through the deployment of DTs in hospitals or hospital departments.

9 CONCLUSION

Due to its integration with Deep Learning, Machine Learning, IOT, and many other technologies, we can conclude from the debate on the development, significance, and future of digital twin technology that this topic is tremendously relevant to the healthcare business.

This idea has a great revolutionary power to transform the entire healthcare architecture globally, from moving the entire workspace from physical medium to digital medium to reducing the risks on doctors and medical staff and even entire populations in case of contagious disease.

It will not only solve the problem of patient to doctor ratio but also ease the process of healthcare architecture to a great extent,the medicine and treatment process will become accessible by most. With the help of deep learning,it will also help in detection of life threatening diseases quite early.

These all importances concludes that this is one of the hottest fields in research and has the capability of great funding and economic transformation. There are some limitations and problems like high computation needs, data vulnerability and high cost in development but they are being addressed as this technology and its use in this domain is being taken seriously by some global companies and even opportunistic startups.

Finally, we look forward to a great future this technology has in healthcare. It can be the transformation of experimental virtual surgery on 3D replication of organs to reality on natural organs or may be development of real time organs using collaboration of this technology with 3D printing.

KEY TERMS

- **BERT:** Bidirectional Encoder Representations of Transformer
- **GAN:** General Adversarial Networks
- **MLP:** Multilayer Perceptron
- **CNN:** Convolution Neural Networks
- **IOT:** Internet of Things
- **RNN** Recurrent Neural Networks
- **DBSCAN:** Density Based Clustering of application with Noise

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