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Research Paper

Exploring the revolution in healthcare systems through the applications of digital twin technology

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ABSTRACT

Digital Twin is a virtual replica of an item that is gaining traction in several sectors. This technology is creating significant advancements in the field of healthcare. A machine or a person's digital twin is a virtual replica of that entity. In order to create a digital model that can be tested and simulated, one has to gather enormous volumes of data through Internet of Things (IoT) sensors for the associated application. Based on the patient's lifestyle, regular eating habits, and blood sugar data, this technology helps to warn the patient about prescriptions, dietary adjustments, medical consultations, and other situations. Digital Twin uses a substantial quantity of data from multiple IoT devices and uses Artificial Intelligence (AI)-powered models. Patients' own Digital Twin uses previous data insights to help select the most appropriate medication, forecast the results of a particular surgery, and control chronic illness. The main aim of this paper is to study Digital Twin and its need for the healthcare sector. This Paper discusses various features and services of Digital Twin for Healthcare. Various technologies and tools of Digital Twins for Healthcare are also briefed and further identified and discussed, along with significant applications. The healthcare sector has realised to create a framework focused on the patient. In the future, healthcare should think about more advanced ways to provide best-in-class treatment to the patient. Planning for the post-digital era is crucial as healthcare organisations continue their digital transformation initiatives.

1. Introduction

A virtual replica of a product or system is called a "digital twin" throughout its life cycle. Digital twins provide learning, reasoning, and dynamic recalibrating for improved decision-making using real-time data and other sources. They are intricate computer models that can be modified, changed, and updated in real-time and are twins, or exact reproductions, of real-world things. With the use of digital twin technology, medical practitioners may advise patients on preventing certain diseases and being ready for medical crises [1–3]. Digital twins are exact simulations of the thing or person they are simulating. The development of realistic digital twins benefits from the pertinent data provided by healthcare specialists. Patients may prevent medical crises by using simulations that identify illness signs early. They can recognise the potential for illness relapse, such as in the case of cancer. The predictive capabilities of the digital twin may also spot lifestyle trends and warn users of unusual behaviour that can damage their health [4,5].

By providing proactive patient care, healthcare practitioners can increase patient quality of life. Digital twins are now used in healthcare, relying on AI and Machine Learning (ML) technologies. Integrating AI and ML features with cloud apps, digital twins may utilise real-time data to create precise predictions about people's health outcomes [6–8]. The digital twin of the healthcare paradigm is interactive and more straightforward for people to comprehend. Patients participate in the digital twin, which motivates them to lead healthier lives. Using a digital twin to compute medical data promotes transparency and builds confidence throughout therapy. As a result, both physicians and patients have better overall healthcare experiences. Compared to other industries, the healthcare sector has more factors at play, which makes it challenging to create an appropriate care strategy for capacity planning. They have a digital twin of their organisation, which allows them to make educated choices regarding capacity, investments, and personnel [9–11].

The continual data transfer enables a real-time digital representation of a physical object, enabling the virtual and actual objects to coexist. The

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development of a digital representation, gathering and archiving of real-time data, and providing insightful information based on the obtained data are all made possible by integrating four technologies into a digital twin application. Digital twin technologies include the IoT, Extended Reality, Cloud, and AI. Medical device producers may test their goods in various settings without spending extra money using simulation technology [12–14]. Researchers and engineers may find possible design defects early in the prototype phase by using a virtual model of a medical device. Furthermore, by engaging with 3D representations of human anatomy, users can see how the gadget would operate in actual use. The use of digital twin technology in medical device production enhances design effectiveness and regulatory compliance [15,16].

Digital twins differ from previous computer models in that they get accurate and timely data and constantly communicate with the object they represent. A digital twin of a computer manufacturing facility would receive real-time data from sensors incorporated into the production equipment, and so on. When we contemplate using digital twins in domains like customer service, other exciting possibilities come to light [17–19]. A digital twin might help e-commerce businesses analyse trends and customise websites or applications to suit each consumer's interests. Alternatively, they could actively and passively reduce customer annoyance through customer support [20,21]. The main aim of this paper is to study the various capabilities of Digital Twin in the healthcare field.

1.1. Digital twin

A digital twin is a virtual representation of an actual item. A digital depiction of possible or real processes, people, locations, systems, and gadgets may also describe it. In 2003, when digital representations of tangible objects were still in their infancy, the term "digital twin" was first used in the context of product lifecycle management. It is a virtual representation of a device that is interactive and continually collects data using software and embedded sensors. This allows us to see the exact real-time condition of the gadget. When computational technologies like AI are used, we may even be able to anticipate potential problems before they happen, allowing for quick repair or replacement of crucial components [22–25]. By offering a product as a service, digital twins allow firms to develop new business models and break into new industries. This strategy works well for pricey assets that other businesses may want to avoid possessing. In contrast, the maker, who owns the item, is responsible for its usage, productivity, and upkeep. By building a digital twin of an existing product on the market, manufacturers may track activities, gather information on the constellation of circumstances that signal the device needs repair, and start developing predictive maintenance models [26–28].

1.2. Need of digital twin in healthcare

Digital technologies have been swiftly adopted by the healthcare industry, boosting overall human experiences and reinventing how operations should be carried out. In order to obtain the required infrastructure and knowledge, conventional healthcare providers are developing long-term collaborations with technology companies as virtual healthcare services gain popularity. The global healthcare industry is becoming more robust as it overcomes COVID-19's obstacles. However, the pandemic's profound effects have changed it, and it is now motivated by the fresh possibilities they have made apparent [29–31]. Hospitals and patients face significant challenges due to unforeseen workload changes and test cancellations. When needed, imaging technology should be functional and accessible. System failure-related unplanned downtime may be costly, increase patient wait times and discomfort, and hurt treatment results. So, there is a need to take up various challenges in healthcare using Digital Twin [32,33].

There is an increasing need for medical supplies and drugs. Costs associated with development are increasing along with time to market and profitability. Millions of people throughout the globe now have even less access to therapies that might save their lives. Such problems are addressed by creating technology-based solutions to evaluate medical devices, eliminating human trials throughout the development phase, and making the procedure quick, safe, and affordable [34–37]. The best results from digital twin technologies come through collaborative usage. To construct a high-fidelity, efficient digital twin, cooperation is needed from hospital executives, physicians, administrative personnel, the building architect, and the technology partner. The interdisciplinary team regularly assesses the digital twin to ensure it offers solid insights and enhances hospital operations efficiency [38]. A digital twin may reduce the need for expensive modifications once a department has been reorganised and can help plan adjustments or additions to care units [39–43].

1.3. Research objectives

A digital twin is a computer-generated replica of that system or thing. A software object or model mimics a sure actual thing, process, organisation, person, or other abstraction. A composite representation of a range of real-world things and processes may be created using data from several digital twins [44,45]. Digital twins will increase their attention on systems and procedures associated with finance, supply chain, manufacturing, and logistics as they expand [46–49]. The primary research objectives of this paper are as under.

RO1:to study Digital Twin and its need for the Healthcare sector;
RO2:to discuss features and services of Digital Twin for Healthcare;
RO3:to study available technologies and Tools of Digital Twin for Healthcare;
RO4:to identify the significant applications of Digital twins for Healthcare.

2. Various features and services of Digital Twin for Healthcare

The various associated services and concerns of Digital Twin technology for healthcare are represented in Fig. 1. It reports the smart services of this newest supportive and advanced practice, i.e., digital twin for the healthcare domain. It mainly focuses on the services in terms of patient's health, data-related facts and concerns, reduction in servicing costs associated with the treatment and care of the patient, qualitative services, societal disruptions related issues, etc. These services further reflect the betterment in the patient's care throughout their treatment to get a heal-up with quick recovery [50–54].

Every healthcare organisation strives to improve patient experiences while simultaneously boosting the effectiveness, throughput, and quality of care delivery. In order to keep things running smoothly, treatment spaces, operating rooms, critical care unit beds, and patient rooms are all finite resources that must be scheduled and "turned" regularly. Data from Electronic Health Records (EHRs), illness registries, and other systems and resources may be merged with patient data from wearables and other personal health devices. With these enormous data sets, we can accurately portray each person and perform simulations to predict the effects of various medicines, develop highly individualised care plans, and get early warnings of a patient's susceptibility to illnesses or other disorders [55–58]. Via the advancement of human body modelling and the improvement of medical treatment through digital monitoring, digital twins in the healthcare sector are altering clinical operations and hospital administration. A doctor evaluating an athlete would conduct a computer simulation to comprehend how the system would function in different real-world conditions. The benefit of this approach over preventing re-injury prior to pitch testing is that it is significantly quicker and less costly [59–61].

Digital Twin uses four technologies to create visual representations, collect, store, and analyse data and provide insightful information. These technologies include AI, cloud, extended reality, and IoT. Significant benefits of digital twins include understanding the behaviour of physical

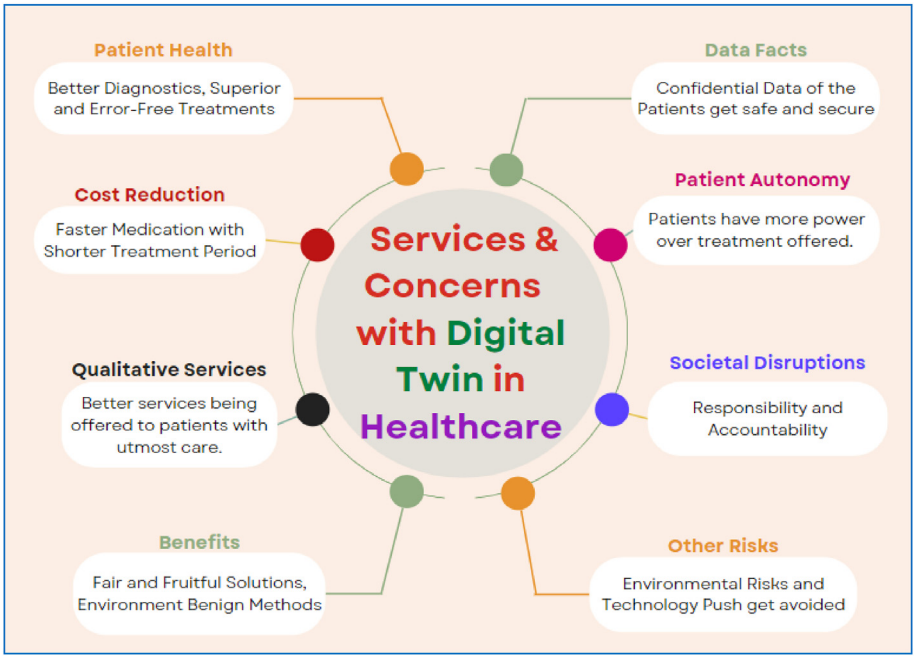

Fig. 1. Services & concerns with digital twin in healthcare.

equipment and remote visibility of assets, systems, and processes. It runs a prediction algorithm using insights from asset behaviour to make future predictions. Additionally, these insights boost efficiency and profitability by automating and facilitating improved decision-making [62–65]. Additionally, it does risk analysis on a variety of what-if situations and helps firms maximise operational efficiency. Gadget digital twins are helpful before and after the device is utilised. Digital twins enable quick prototyping of new or enhanced technologies since they are produced throughout the product development process. AI, ML, and numerical simulations are healthcare entrepreneurs' primary areas of concentration. While each of these technologies makes a substantial contribution to the development of the healthcare sector, they merely scratch the surface [66–69].

3. Various technologies and tools of digital twin for the healthcare sphere

Fig. 2 exemplifies the several smart tools and technologies associated with realising a digital twin for the healthcare sector. The fundamentals and introductory pattern of its services are associated with the various platforms such as; connection-related aspects, simulation models, and model evolution practices; in the case of physical, it relates with the sensing, measurement, materials, dynamics, etc. While performing the analytical process, the concerns of correctness, tolerance, and results are significant aspects of concern [70–73].

Digital twins have many practical uses; therefore, the idea is no longer just science fiction. This technique enables the creation of a virtual

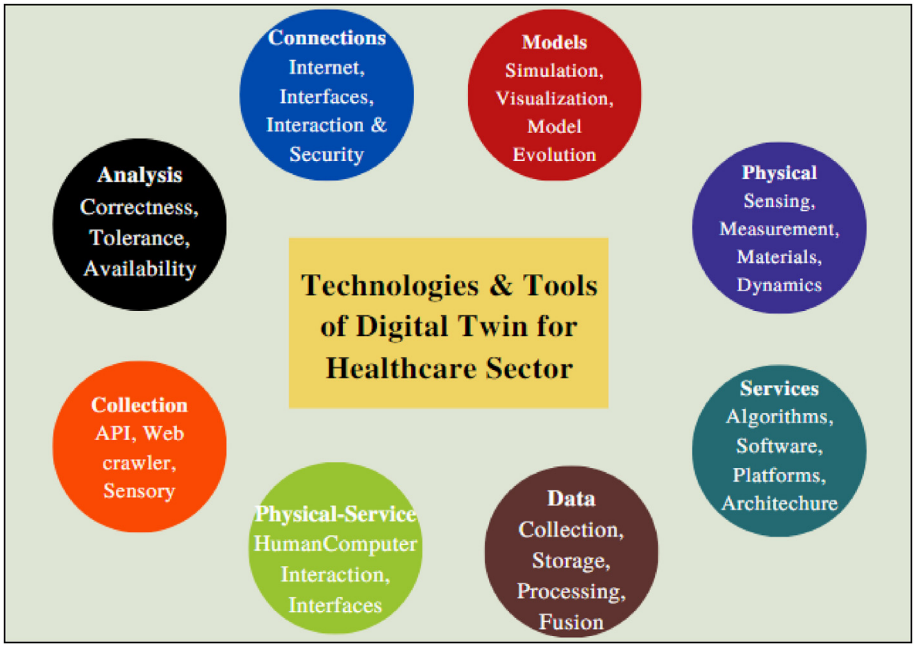

Fig. 2. Technologies & tools of digital twin for healthcare sector.

version of a real-world system or item. A digital twin is used to evaluate how well its physical counterpart is doing. A full-life data collection of any patient paired with AI-powered methods that analyse the data to respond to various clinical questions is a digital twin in healthcare [74–76]. Digital Twin technology will alter as it moves from non-living gear and equipment to biological people. Businesses wanting to innovate and optimise with IoT are increasingly using digital twins. Digital twin journeys may start from a technological position, a problem-solving standpoint, or a user's perspective when interacting with a service ecosystem [77–80].

AI and ML are required for quality control and testing because real-world factors are included in digital twins. Since digital twins depend on a more extensive IoT ecosystem, all sensors and data sources must work together flawlessly. For maximum accuracy and minimal mistakes, considerable data testing ensures that live data integration from many data sources happens without a hitch in real-time. Additionally, IoT testing is crucial for assuring the complete performance of various sensors and devices and the security and compliance of the data acquired [81–83]. Patients getting aerosol-delivered chemotherapy medications risk suffering severe side effects when tumour-targeting therapies fail to reach their targets or "strike" healthy tissue. They successfully simulated the passage of aerosol particles through an adult's upper airway using a digital twin. Additionally, digital twins may help doctors study how to heal human brains [84–86].

4. Digital twin applications for healthcare

Digital twins virtualise hospitals in a medical setting to assist and provide a secure environment for assessing the effects of modifications on hospital performance without endangering the actual location. In order to choose the best course of action and prepare for upcoming issues, a digital twin of a hospital would provide access to data-driven insights regarding operational strategies, capacity, staffing, and care models. A digital twin may continually monitor capacity. As a result, staff schedules may be optimised, precious resources like beds and operating rooms can be allocated, and resources can be swiftly deployed where required. This technology may track, examine, and mimic how the physical object is utilised [87–92]. The Digital Twin transforms into an effective healthcare tool with cloud and AI capabilities. The digital twin combines data from numerous sources to develop a unique model for each patient. This enables medical practitioners to plan the digital twin meticulously and provide precise forecasts and recommendations for specific patients. Cloud technology makes real-time patient data collection possible, and AI components use vast amounts of data to run algorithms and provide accurate predictions [93–102]. Table 1 discusses the significant applications of Digital Twin in healthcare.

A digital twin is used in different ways in the healthcare sector, such as patient operations, medical device or system operations, and healthcare provider operations. Information technology and data professionals may model the operation of an entity before it exists or monitors an existing thing in real time using digital twins, which are highly detailed virtual reproductions of actual equipment, places, or systems. Additionally, the twin helps with data visualisation and how it connects to the thing being modelled. With the ability to completely transform the sector, as it has in other sectors like the automobile industry, digital twin technology has emerged as the appropriate solution for tackling these problems [103–106]. Cloud-based virtual twins provide longer cooperation and numerous crucial technological benefits, such as more efficient research, predictable manufacturing, and proper patient care. Teamwork has recently improved due to shared objectives, making it possible to create vaccinations in a few months rather than more than ten. Manufacturing, engineering, energy, and several other sectors have all seen commercial uses of digital twins, with varying degrees of success in value creation, cost reduction, and efficiency enhancement. The idea of a digital twin is not new, but it has gained popularity recently, especially in the industrial, automotive, and healthcare sectors. Many companies are deploying digital twins to boost productivity, optimise operations, and lower risks because of the competitive advantage they may provide [107, 108].

Digital twins are being created using more potent and sophisticated methods. It is now more productive and less stressful for systems to develop and execute millions of simulation programmes. As digital twins are used more often, more suppliers and alternatives are available, which enables the development of digital twin technology. The range and depth of insights have also expanded because of functionality and ML. The design process may be streamlined, and many prototype testing components are eliminated using digital twin capabilities and 3D simulations and human-computer interfaces like augmented and virtual reality [109–112]. The digital tool helps engineers see possible difficulties with quality, durability, and manufacturability before finalising designs, which expedites conventional prototyping and enables goods to enter production more quickly and inexpensively. Digital twins increase the effectiveness of systems and enterprises, producing better results using data, ML, and the IoT. The real benefit of a digital twin is that it offers real-time data that may help in learning, thinking, and comprehending how objects and systems function. It allows users to more accurately assess, model, and optimise a physical entity's performance across the length of its existence [113–115].

5. Discussion

A digital twin may help study extensive hospital data, such as the schedules of healthcare professionals and other things. The simple accessibility of this data will help with cost minimisation and patient experience enhancement. This is crucial in the healthcare industry because it enables strategic decision-making in a complicated and delicate setting. Entities include systems, technologies, people, locations, and processes. A digital twin makes real-time elements possible via operation and monitoring simulations. To enhance operations and determine the effects of substantial changes, a digital twin helps imitate real-world settings and analyse how it reacts to changes. The digital twin analyses a person's data, assess illness symptoms and contrasts them with reported patterns. To provide correct results, it uses algorithms and adaptive analytics, which are constantly updated to improve data collecting and curation skills. Modern technology and the virtual twin of the patient help doctors with remote patient monitoring. Patients will have easier access to healthcare, giving their families daily assurance and peace of mind.

To choose the optimum medicine or drugs for that particular scenario, Faststream Technologies built a Digital twin with hundreds of options. As a result, it is possible to test new prospective medications on a digital group of patients with varying genotypes and symptoms to determine which one will be the most effective and the best dose. The number of clinical trials needed will decrease as the number of trials increases for the Digital Twin application in healthcare. Businesses can monitor equipment status at distant locations and optimise product designs with the help of Digital twins. Organisations may make choices immediately affecting their key performance indicators by exchanging and synthesising digital twin data. Making machines may be an expensive and time-consuming procedure. Assembling a prototype from components that have yet to be designed or tested together may often lead to issues. Presuming everything will function properly may require a lot of resources and labour. Digital twins, virtual-based physics machines that can simulate a device's behaviour in real time by analysing data, were developed to solve this problem. A digital twin is helpful in many different contexts. A single sensor within a device is modelled and represented by digital twins from one angle.

The firm uses various technologies, including digital twins, statistical analytics, simulation, and others, to construct virtual patients. These models replicate human anatomy, which subsequently aids producers of medical equipment. Digital evidence is used instead of clinical evidence across the product development lifecycle, saving money and resources.

Table 1
Digital twin applications for healthcare.

S No	Applications	Descriptions
1.	Patient care	Researchers can better comprehend personalised medicine, patient care, and the treatment of chronic diseases with the deployment of Digital Twins. The development of digital twins for the human body as a whole and specific organs like the heart, lungs, and kidneys are advanced. This may mimic any particular person's organ, enabling complete testing before implementing the findings on the patient. Utilisation models and digital twins may help boost the resources' availability. Recognising and moving objects increase room turns, speed up admissions, and enhance patient outcomes. Digital twins also make it possible to do predictive maintenance, which improves the performance and accessibility of less expensive assets, including cheaper imaging technology, lab automation, and surgical robots. Effective resource management goes beyond medical tools, procedures, and employees. It may be enhanced at the hospital, campus, or public health network level. The most potential digital twin users in healthcare may be personalised treatment. Applications for digital twins are currently extensively employed across several sectors. By offering precise virtual representations of things and operational process simulations, digital twin solutions help various industries uncover opportunities for innovation and enhance corporate operations and performance.
2.	Clinical studies	The usage of digital twins may change how clinical studies are managed. The use of digital twins allows for the speedy identification of the most promising research directions, which has changed how early-stage studies are conducted. It is possible to create a clinical trial participant's twin, which enhances compliance, communication, and the ability to create alerts and reminders to keep everyone informed and on schedule. For instance, the Digital Twin may reduce the required participant numbers by virtualising the control group. Incorporating IoT devices and telemedicine procedures to allow virtual participation and increase the geographic diversity of trial participants may help increase participation. In contrast to digital simulation, which is dynamic and gets real-time updates from a physical asset, system, or process, a digital twin is static and does not. As a consequence, it produces results for business choices that are more accurate. The patient's Digital Twin is designed to continuously gather information on the person's numerous vital signs, medical condition, response to treatment, and environment. The ML algorithm helps each patient's previous and current data anticipate their future health issues.
3.	Better personal health results	Rising computer and algorithm power in the healthcare industry enables technology to develop a patient-specific digital twin, allowing for human variety and enhancing individual health results. To fully realise the potential of the digital twin, additional coordinated and ongoing fundamental research and development will be needed. It helps firms operate better by visualising complicated assets and procedures. With a digital twin, automatic data flow between the actual physical item and its digital representation is conceivable. The doctor may choose the optimal treatment from surgery, radiation therapy, or hormone therapy using a digital twin with the patient's imaging data, genetic information, and laboratory findings. Analysing physiological and behavioural data, Digital Twin assists in the early diagnosis of chronic illness to manage chronic disease in a large population. A complicated system, process, or location may now be represented by a digital twin instead of just a single item or component, using advancements in artificial intelligence technology. Such simulation optimises the procedure and enhances the patient experience by lowering lengthy wait times, efficiently managing emergency services, maximising the use of lab and medical equipment and staffing needs, and minimising device downtime. Consequently, hospital managers can keep an eye on everything from patients to physicians to data to processes from a single platform.
4.	Enhancement of Hospital activities	The enhancement and optimisation of the whole ecosystem are facilitated by using digital twins for different hospital business activities. It mimics various hospital operations, including the movement of staff members, patients, and equipment. It tracks systems, assets, and people according to location. The AI model may simulate increased efficiency by using the real-time data available from all hospital data points. The model method may aggregate the outcomes of both imaging and non-imaging-based laboratory diagnoses and offer them to the doctor to aid decision-making. Before trying scenarios in locations or conditions similar to real life, researchers test them using digital twins cost-effectively and safely. Engineers and manufacturers often use digital twins, but researchers are now seeking to translate those ideas to the health field. Researchers may use digital twins to spot illness patterns, model the effects of therapies, and pinpoint the most promising areas for further study in living subjects. A large cohort of medical twins can be compared using digital twin technologies. In addition to comparing and evaluating various treatment choices for individuals with similar features like age, gender, ethnicity, and even underlying illnesses, this may help identify biological indicators for disorders.
5.	Diagnostics and medical training	A Digital Twin is a patient model developed before the actual surgery. A multidisciplinary team carries out virtual surgery in medical training and diagnostics to prevent harm to human anatomy. Residents may mimic surgery on patients using this real-time model to learn more about individuals' physiological and anatomical variations. In addition to helping to create high-resolution, disease-specific medical digital twins that doctors and researchers can use for a variety of other applications in the healthcare industry, the same technology being used to comprehend long-term symptoms can also be used to help create medical digital twins. Hospitals and research facilities all across the globe will benefit from AI-driven research and digital twins, allowing the widespread use of technology to enhance health, education, and economic opportunities. Digital twins will be used by many more businesses and sectors to digitise their operations, and they will need a distributed, hybrid, multi-cloud environment. They will need a technology partner that can provide the proper hardware, software, and integration services for data management while safeguarding their data, simulation, and the actual product, procedure, or person it represents in the real world.
6.	Healthcare forecasting	Demand for digital twins in the medical industry has soared because of the promise of tailored treatment, remote patient monitoring, and health prediction. This plays a vital role in healthcare forecasting. Additionally, care arrangements, operational plans, and personnel support hospitals in cutting costs and enhancing patient care by employing the Digital Twin model of the hospital. A digital twin is a real-time digital representation of an item or process that incorporates all the current information and is updated as new data becomes available. With this technology, researchers may run millions of individualised therapy simulations using the information on the patient's genetic makeup, medical history, and long-term effects. This enables researchers to identify the most effective therapy approach without endangering actual patients. A complex ecosystem of interrelated moving pieces, including hospitals, develops to meet the requirements of patients, carers, and healthcare professionals. Patient admissions and discharges occur often. People go to visit their families. Healthcare professionals move between patients and wards. Continual deliveries of supplies are made. Keeping track of all that activity and mobility is challenging. Hospitals will be under additional strain, making it more difficult to optimise operations, manage hazards, distribute resources efficiently, and maintain everyone's safety and security. These various challenges can easily take up by Digital twin.
7.	Better Clinical research method	Clinical research techniques may change as a result of digital twin technologies. Without jeopardising the health of real-life people, users may utilise technology to ask better questions, obtain better responses, and extract actionable insights. More digital twins result from more data, which leads to more discoveries and improved care. Data holds the key to the future of medicine. Digital twin AI-driven algorithms should be able to identify irregularities in a person's behaviour or lifestyle choices, connect various clinical occurrences, track responses and reactions to a particular drug, and correctly interpret all of this data. Healthcare professionals may test using algorithms and the associated digital twins before acting, but the technology must be examined for viability and quality. Hospitals are forced to adopt digital advancements in particular circumstances without considering the effects. There are many

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Table 1 (*continued*)

S No	Applications	Descriptions
		ambiguities and paradoxes as a consequence of this. Hospitals are being put under increased pressure to incorporate digital technologies, but there are growing worries that doing so may lead to more fragmented ecosystems.
8.	Identify the best treatments	Assembling cohorts of similar patients in real life would be difficult or costly. Technology also avoids employing humans with their dangers and consent dilemmas. When appropriately implemented, digital-twin technology in the healthcare industry enables physicians to choose the best treatments, enhance patient outcomes, and work as efficiently as possible, saving hospital costs. The walled structure of their operational models or the interoperability challenges surrounding diverse health information systems hinder hospitals under growing pressure to create a real-time health system. The need for a more coordinated, integrated, and comprehensive strategy for digital transformation has been brought to light by these conflicting demands. Thus by converting operations that previously depended on linear transactional interactions into ones that can be carried out in parallel, digital twins this. For instance, using digital twins enables hospitals to automatically initiate notifications based on sensor information rather than requiring a user to do so. Patient flow and emergency department wait times may be decreased, cutting expenses and enhancing the patient experience.
9.	Enhance medical innovation	In the healthcare sector, digital twins may enhance medical innovation and regulatory clearance. In the future, this technique could assist physicians in optimising the efficacy of treatment approaches tailored to individual patients. Digital twins may help medical professionals bring life-saving technologies to market more quickly, cheaply, and with higher patient safety. To develop digital twins, individual and demographic data are incorporated into computer-based or in silico models. These virtual models of human physiology help scientists learn more about illnesses, novel treatments, and medical equipment. More lives may be saved by using digital twins to forecast and avert patient crises like cardiopulmonary or respiratory arrest, generally known as code blues. Digital twins give smart hospitals chances to save lives while saving money by using a real-time, people-centred approach to issue resolution and generating long-term value. Traditional community health programmes call for a wide of a patient with a chronic illnesses, such as ongoing respiratory issues or lung disease. However, complicated phenotyping processes that can invariably be matched to medicine and the dose for a patient are needed for a doctor to make therapeutic decisions. This technology enables the more complicated difficulties often not covered by conventional chronic illness programmes.
10.	The best course of therapy	A digital twin may be used to forecast how an operation will go. It may help choose the optimal course of therapy for a particular patient. Whether it is enhancing the efficiency of assets or processes or cutting down on wasteful expenses, the advantages of digital twin technology are widely established throughout sectors. The enabling technology will be connected with the physical asset inside the digital twin for real-time data flow from IoT devices to produce a digital twin. Patient's Digital Twin solutions from fast-stream technologies use several health data sources, such as in-person measurements, imaging records, test findings, and genetics, to help diagnose. The available clinical data will be used to replicate the patient's health condition in the whole-patient twin model, and statistical models will be used to infer the missing parameters. A digital twin, for starters, hastens the creation of novel items. A virtual template would replace the manufacturing process, eliminating the requirement for a costly prototype. A digital twin tracks a product during its entire existence. All data is analysed by the digital twin, which also continuously raises the standard. In addition to enhancing the finished product, these sensors make predictive maintenance possible. The cloud-based continuous control data transmission enables anomalies' rapid and straightforward identification. They can also predict when maintenance is necessary based on use and wear and tear.
11.	Research and development	In the healthcare industry, digital twin simulations are used to build models that provide data for research and development. Doctors use it to assess and reassess care delivery methods, capacity, personnel, and other factors. Using a biophysical model, a digital twin in healthcare may track and examine a patient's data. A doctor may provide the most cutting-edge care while remotely managing a patient's healthcare by analysing that patient's past and present data. Digital twins use ML methods to change healthcare procedures and enhance patient satisfaction. All Digital Twin apps utilise the IoT as their leading technology. IoT is built on the gathering of data utilising sensors from physical items. The real thing is then digitally recreated using this data so that it may be examined, modified, and optimised. Therefore, the information flow across a system controls the value produced by the IoT. Digital Twin applications may link a virtual representation in real-time with a physical item, continuously updating it using IoT. While utilising cloud computing technology, data may be efficiently stored and retrieved online. Since Digital Twin applications work with enormous amounts of data, cloud computing enables all data to be saved in the virtual cloud and simply accessible from any place. A powerful analytical tool known as artificial intelligence can automatically analyse data and provide relevant insights. Additionally, it can predict likely outcomes and recommend avoiding such problems.
12.	Prediction of the result	Before choosing a course of treatment, digital twins mimic medical operations to predict the results. Additionally, rather than performing surgery on an actual patient, it can be done on a simulated patient using a virtual replica of their organs. The examination of a patient's medical information and the functioning of medical equipment under varied circumstances are made more accessible by digital twin technology in medicine. Every therapy depends on the functionality and importance of the equipment used in different medical procedures. Before an actual complex product is made, digital twin technology creates a virtual replica that may be tested and improved. Businesses may use digital twins to simulate and evaluate each stage of development before producing the final product to discover problems and likely failures. Twin Engineering collaborates with development teams to help them comprehend how potential modifications to the manufacturing process may affect the production outcomes and to assist them in modifying their manufacturing processes to create improvements that are precisely targeted. Manufacturers may improve operational processes while concurrently cutting overall engineering costs. Twin operations management improves operational efficiency, anticipates maintenance, and performs dynamic simulations. IoT sensors integrated within the physical asset continually transmit dynamic, real-time data about the asset and its status. Employees can control and monitor manufacturing processes and assets digitally.
13.	Possibilities for effective treatment and diagnosis	Whole-body scans are regularly recommended to patients to help medical professionals make diagnoses and provide more precise treatments. However, these scans are incredibly costly and involve much radiation, which might raise cancer risk. Consequently, more recent technologies like digital twins and AI-based examinations are being used. They are more patient-accessible and provide a more thorough and secure diagnostics technique. IoT sensors in a digital twin system provide big data in real-time, enabling organisations to analyse their data and proactively identify any system errors. With this technology, businesses can more precisely schedule predictive maintenance, enhancing the efficiency of their production lines and lowering maintenance costs and getting a detailed, real-time picture of an extensive physical system. On the other hand, having access to a digital twin enables users to administer and monitor system performance remotely. Increased productivity and operational efficiency result from technicians concentrating more on inter-team cooperation using process automation access to system information. Businesses can decide whether or not to make changes to a manufacturing value chain more quickly and effectively because of the availability of enormous amounts of real-time data and powerful analytics.
14.	Identify and report dangers	Because the digital twin can perfectly mimic and forecast outcomes, people may switch from treating diseases to sustaining healthy lives. Critical patient information, such as early health signs, is included in the digital twin. In order to evaluate risks and advise patients on the risky behaviours they should avoid leading healthy lives, it incorporates data on early health indicators. Healthcare practitioners assess the effectiveness of preventative programmes for particular patients using ML technology. This is because they advise people on the best actions to preserve their well-being. Healthcare professionals have a low-risk environment to evaluate their

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Table 1 (*continued*)

S No	Applications	Descriptions
		suggested tactics and their effects on hospital operations using digital twin or virtual models. Because it gathers and combines data from numerous dispersed sources throughout the organisation, it successfully addresses the various problems of conventional siloed and complicated healthcare units. Forecasting bed demand enables healthcare professionals to maximise capacity and decrease wait times. Manual patient flows could be more efficient and sometimes paper-based. Several constraints, including an ageing workforce, escalating regulatory requirements, and slimmer margins, are increasingly limiting hospital, clinical, and facility operations. It is more crucial than ever to optimise operations to enhance patient care as the demand for ambulance services rises. Ambulance authorities must now provide more services with fewer resources in a constantly changing environment, and they usually depend on antiquated legacy systems that are primarily manual and unconnected.
15.	Emergency situation forecasting	A hospital's organisation may better provide preventive maintenance while offering individualised health care expenses by using digital twin technology to help forecast crises like cardiopulmonary and respiratory arrest. By building a virtual twin of a hospital, administrators, nurses, and physicians may gain a thorough, real-time examination of the ins and outs of patients, improving their understanding of processes. The wait time for patients is decreased by a good workflow, which also manages appointments and ensures precise inventory consumption and maintenance. The hospital decided to work with Healthier to build a digital twin of the radiology division to solve these problems. In order to find areas for improvement, the cooperation team built a model of present radiology processes and looked through existing layouts. The digital twin image allowed the hospital to simulate several scenarios, decide on the most efficient use of resources, and stress-test the actual structure. Improvements that formerly required weeks or months of trial and error may now be made quickly. While generally linked to asset-intensive sectors, digital twins may also be used in healthcare. As a result, problems that patients and hospital personnel were having may be found and fixed. A more comprehensive and long-term solution will be possible if essential issues in the healthcare sector are understood, especially from the patient's viewpoint.
16.	Increase patient satisfaction	With the help of a digital twin, healthcare organisations may find new methods to enhance and expedite procedures, enhance patient satisfaction, save costs, and raise the value of treatment. The digital twin creates models of physical space and processes. The cost and quality optimisation parameters are then looked at and eventually chosen based on the insights from simulations utilising the digital twin. With the help of supplementary technologies, digital twin insights may be strengthened even further. These technologies provide a trustworthy data source and a way to evaluate layout, process, and other improvements. The success of a digital twin depends on a solid collaboration between the hospital and a technology company that is aware of the clinical, workflow, and financial needs of healthcare professionals. One may model human behaviour and other variables to find the best solutions to catastrophes like floods, fires, and pandemics. It may recommend steps to enhance results as the situation changes. Before going to the development laboratories, scientists may digitally construct a full-scale production process and test their compositions using the digital twin. This method increases productivity, decreases waste, and minimises batch-to-batch variability while drastically lowering the cost of creating novel ways. To save historical knowledge from being permanently lost, digital twins have the potential to alter education as well as the preservation of and interaction with our historic sites.
17.	Making intelligent operations	By allowing intelligent operations, real-time analytics, real-time information orchestration, and improved overall situational awareness, a real-time health system uses technology to improve results for patients and healthcare organisations. Digital twins are virtual representations and reproductions of resources, procedures, systems, or organisations in man-made, social, or natural contexts. They help organisations by supplying real-time insight into the behaviour of complicated physical assets and people, enhancing decision-making and streamlining procedures. Because they may provide a significant quantity of real-time data and enable real-time interaction with the physical twin, digital twins fundamentally differ from computer models. Actions and events may be modelled simultaneously with unparalleled precision, enabling experimentation in a real-world setting away from a live environment. The physical and digital worlds are connected via technology. Scientists and engineers may gather a plethora of data using sensors to measure a physical asset, which can then be turned into a virtual model. It is possible to analyse this data-driven model to get vital information on how the actual object will behave in the real world. A digital twin may assist us in understanding the current performance of a system or product and its potential future performance.
18.	Identify patient and process issues	In reality, particular digital twins may be utilised to increase operational efficiency, optimise procedures, enhance the patient experience, lessen staff fatigue, and provide better patient outcomes by employing a unified real-time model to predict patient and workflow issues. Smart hospital digital twins provide suggestions on enhancing results and more insight into past, current, and future hospital performance. Thus to build a digital twin, sensors gather detailed real-time data from physical components. This information is then utilised to create a digital duplicate that may help teams better comprehend and analyse real-world systems or things. Leaders should be aware of this idea and try to put it into practice. Additionally, the IoT has increased the availability of digital twins for many firms, enabling enterprises from other sectors to profit from this technology. The whole trip from the physical world to the digital world and back again is made possible by a digital twin. A digital twin helps decision-makers see and understand the context of company data and the actions they take in response to it. Technology businesses describe digital twins as the virtual representation of a real thing or system throughout its existence. In order to provide learning, reasoning, and dynamic recalibration for improved decision-making, it uses real-time data and data from other sources.
19.	Remote patient assistance	Physicians may remotely monitor patients with the help of Fast stream Technologies' Digital twin of the patient. While continually improving data collecting and curation skills, it uses adaptable analytics and algorithms to generate reliable findings. We can keep track of patients using smart wearables. Real-time data from our cloud-based digital twin will be fed via more diminutive, more comfortable wearables with sensors. Thus, with an adequate understanding of the course of the illness and ongoing patient data collecting through fitness trackers. Hospitals are successfully using digital twins on an organisational level. By building a digital twin of a hospital, managers, physicians, and nurses may get significant, real-time insights regarding patient health and processes. Digital twins provide a better approach to analyse operations and warn the appropriate people at the appropriate moment when instant action is necessary. Sensors monitor patients and coordinate equipment and employees using digital twins. Manufacturing, smart cities, retail, the automobile, oil & gas, aerospace, mining, and healthcare sectors are just a few of the sectors that have embraced digital twin technology. There are several possibilities available in these fields. Data from IoT and Digital Twin Applications in Healthcare will now be crucial for the growth of healthcare and medical businesses. Fast stream Technologies' digital twin solutions might assist healthcare organisations and experts in determining the best method to improve and streamline processes, improve patient experience, reduce operational costs, and increase the value of treatment.
20.	Therapeutic trial	Depending on specific traits, medical researchers might use digital twins to specify which individuals. This technology can help in therapeutic trials and predict the results and adverse effects in actual patients. To increase the effectiveness of cardiovascular therapy, healthcare practitioners, regulatory agencies, and medical device makers are working together. A smart hospital digital twin introduces a novel approach to modelling, managing, and acting on hospital data. The capacity to analyse every aspect of a hospital, including data, processes, patients, and physicians, is a strength of hospital management. The development of digital twins in recent years has made them particularly suitable for usage in hospitals. Technology has offered enormous opportunities for tackling fundamental difficulties in today's healthcare since hospitals are full of "connected" or "connectable" objects that may be united in a digital twin. The regions and operations where the elements for cost and quality optimisation are investigated are given a physical

(*continued on next page*)

Table 1 (*continued*)

S No	Applications	Descriptions
		representation via digital twins. Fast stream Technologies have developed a digital twin model that hospitals and administrators may use to analyse patient insight and outsight in real time and prescribe an appropriate workflow plan for nurses and physicians. While keeping track of appointments, maintaining proper inventory processes, and lowering patient wait times, helps.
21.	Digital monitoring of the human body	Digital twins are revolutionising clinical procedures and hospital administration in the healthcare sector by improving medical treatment with digital monitoring and human body modelling. Operating rooms, staffing, and bed shortages may all be improved with a digital twin. The improvement of patient care, cost, and performance will be made possible by access to this data. In order to establish a risk-free environment for studying the impact of modifications on system performance, digital twins may virtualise the hospital. This is crucial in the healthcare industry because it enables making sensible strategic choices in a very complicated and delicate setting. Digital twins employ sensors connected to accurate items to gather and transmit information about those exact things. Making equipment in a virtual environment for design, testing, and manufacturing is the digital twin's ultimate aim. Following the development of digital twins, technology has improved to incorporate more solid objects like buildings, factories, and even cities. A digital twin's basis or starting point is data mining. The system's data mining is utilised to track performance. The digital twin decides based on reality as opposed to fantasy.
22.	Individualised treatment	By simulating a person's genetic makeup, physiological traits, and lifestyle, this technology may also be utilised to develop personalised treatment. It is more individualised than precision medicine, which usually focuses on bigger sample sizes. The digitisation of the human body and the construction of exact reproductions of its internal organ systems are intended to advance medical practice and patient care. Doctors may benefit significantly from the use of digital twins in organ modelling, including the identification of previously undiagnosed diseases, the testing of medicines, and the enhancement of surgical planning. It might be challenging to keep track of all the equipment and find it quickly in complex organisations with many offices, such as hospitals, businesses, and ports. For instance, a digital replica of a hospital may help staff members locate a specific piece of equipment in an emergency. The Digital Twin system continually collects information about the current location of assets through the IoT sensors embedded into every piece of equipment. Businesses may use a digital twin to test and verify a product before it is produced. A digital twin helps engineers to identify any process faults before the product is put into production by mimicking the anticipated manufacturing process. Engineers may manipulate the system to cause unexpected occurrences, analyse how the system reacts, and develop mitigation strategies. This additional capability improves risk analysis, expedites the development of new products, and increases the reliability of the production line.
23.	Monitor healthcare facilities	Digital twins may be used in the healthcare industry to replicate items, monitor healthcare facilities, and foresee issues before they arise. They are also valuable tools for data visualisation, improving access to and comprehension of stored data about an item. Several businesses may profit significantly from digital twins, but such data is needed to work well. Businesses may utilise IoT devices to generate and transmit enormous volumes of data from physical items like buildings and large equipment to make digital twins of such assets. A digital twin could help healthcare systems encounter several significant operational efficiency problems. Long lineups, incorrect transcriptions, broken equipment and technology, and lack of multidisciplinary cooperation are a few examples. Thus to assess the impact of modifications on system performance in a risk-free setting, a hospital may be virtually recreated using digital twins. This is important in the healthcare industry because it allows for strategic choices with knowledge in a delicate and complicated setting. Additionally, digital twins provide much-needed accuracy, consistency, and clarity to today's disorganised medical records. When integrated, they give a more thorough account of the illness and its treatment, enabling robust technologies like artificial intelligence to provide more accurate insights. All patients, even high-risk patients who have to or choose to stay at home, may now access accurate and prompt diagnosis and treatment.
24.	Control of patient's essential data	With the aid of a biophysical model, the digital twin is currently being utilised in the healthcare sector to monitor and manage a patient's essential data. Healthcare practitioners may provide effective therapy while remotely controlling the patient's health by fusing sensor data with cloud-based analytics. Using a virtual simulation of the patient's organ, the surgeon and other healthcare experts may analyse medical issues and practise operations in a controlled setting. Digital Twin helps illustrate different IoT or physical device features. By offering a model, the digital twin makes working with IoT easier. Consequently, a digital twin replicates the actual item that can interact with its many characteristics and capabilities. The significance of linking things or digitalisation has increased across all industries with the arrival of Industry 4.0. IoT development leads to the digital representation of tangible items. A product or thing's present and future are both foreseen under the digital twin notion. The digital twin lowers operating expenses, enhances performance, boosts output, lowers manufacturing costs, and forecasts behaviour. The digital twin will completely transform the old approach to analysing and tracking equipment in combination with sophisticated analytical tools and ML.

Services for medical imaging are in great demand right now. Diagnostic medical imaging has become a logistical headache for suppliers all around the globe due to the rising demand for using this technology. A digital twin of the patient is produced utilising information that was previously accessible. Additionally, it is designed to continually gather information about that person's life. A digital twin is designed to assist doctors and other intersecting care technology in really "knowing" the patient to provide more successful care interventions. In the twin, the IoT is a significant piece of technology. IoT devices have made it more affordable to collect operational data. By giving the information that turns the digital twin into an actual twin, the physical assets aid in the construction of the digital twin. The product's performance is improved by sensors built into the physical stock that gather data and send it to the digital counterpart.

6. Limitations

Digital twin technology has to be adopted by all businesses; however, the costs of installation and adoption must be kept to a minimum, or other solutions must be offered to fit every company's budget. This is possible to identify and foresee different dangers and hazards in the physical version of digital twins. For instance, using cutting-edge technologies to address these issues may include employing 5G technology to get more real-time data and keep the digital twin updated with the most recent information. Data must be updated for security protocols. The data from hundreds of distant sensors that connect across unstable networks is what drives digital twin models. Businesses that wish to use digital twin technologies must be able to control gaps in the data streams and reject insufficient data. Users of digital twin technology must adapt to new working practices, which might cause issues while developing new technological capabilities. Businesses must ensure that their employees have the knowledge and resources to operate with digital twin models.

7. Future scope

In future, any sector may benefit from digital twins. To satisfy contemporary expectations, digital twins can hasten the shift to automated and iterative production. For better design, use analysis, and price changes, formerly disparate operations, maintenance, sales, finance, and marketing departments may now access a single source of real-world data via digital twins. In the future, digital twins will become one of the essential IT instruments for the industrial marketplace's digitalisation,

changing the social and political landscapes of many nations. Various challenges in healthcare may be solved with digital twins that go beyond treating symptoms and considering the environment. Digital twins may also be utilised to improve productivity, streamline procedures, find issues early on, and innovate for the future. More hospitals are relying on real-time health systems to assist them in holistically resolving their problems as a result of these difficulties.

Digital twins have a bright future in healthcare, but their actual influence will be known once they can effectively and widely transform data into reliable clinical advice. Mobility in inpatient treatment is made possible by integrating medical tablets and cart computers with digital twin technology. Data from numerous subsystems and in-the-moment interactions between people, processes, and related items are combined to create a smart hospital digital twin. It offers a contextual model of a hospital's previous, current, and forecasted future states that can be adjusted, examined, and improved as AI/ML develops. Multiple parties, both internal and external, will work together to make the digital twin function. The efficient digital twin will be helpful for clinical personnel, hospital employees, receptionists, appointment setters, administrative team members, hospital architects, and a committed, skilled technology partner.

8. Conclusions

A digital twin is a virtual version of a real thing that may be tracked, studied, and improved. When a material thing is represented digitally, it is ‘live’ and ‘dynamic’, which means it updates the fundamental object changes anytime. It can also pick up knowledge from other people, machines, and its environment. The model is created utilising visualisation tools to show data gathered from embedded sensors and IoT devices, which is then analysed using ML and big data analytics. By allowing people to acquire reliable medical advice, book appointments with qualified medical professionals, electronically transfer prescriptions to pharmacies, and access doctor's notes and video appointment recordings online, digital twin technology dramatically enhances patient care. With digital twins, it may be simpler to customise medical treatments for people based on their genetic makeup, physiology, family history, previous behaviours, and other characteristics. With the aid of a digital twin, healthcare professionals may rearrange departments and assets and see how changes affect the simulated environment. The twin presents a comprehensive view of the hospital's functions since it replicates many aspects. Utilising robust data sources like Real-Time Locating Systems may improve the efficacy of a digital twin of a healthcare institution. The data produced by this technology may be utilised to forecast equipment and resource availability and swiftly evaluate the effects of simulation-recommended modifications in the real world. The healthcare sector is quickly transforming into the digital age. Patients now actively seek value rather than just being passive healthcare receivers. This technology is helpful for the improvements and the widespread use of smartphones. Patients and their families have more access to medical information than ever before.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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