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REVIEW PAPER

An insight in the future of healthcare: integrating digital twin for personalized medicine

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Abstract

Purpose An increasingly popular concept in numerous fields is a digital twin, which is a virtual counterpart of an object. This technology is causing important advances for the benefit of patients in the context of healthcare. A digital twin is a computer-generated depiction of an actual product that mimics its information model, action, interaction processes, and product, as well as examines how they might be used to improve the organization of health care and the constraints linked to this innovative technology. This paper will investigate the utilization of Digital Twin systems, processes, and products, as well as examine how they might be used to improve the organization of health care and the constraints linked to this innovative technology.
Methods For research on Digital Twins and their use in healthcare published recently, a brief overview of the literature was reported. The databases of this study are published from 2002 to 2023 and the review was written in English. The Digital twin technology which does not support the Healthcare studies was excluded. This assessment is focused on their contribution to the Digital Twin, which aims to enhance user experience in healthcare from a system engineering and human aspects perspective.
Results The Digital Twin in healthcare has been growing since 2002 from 0 studies to 25 in 2023, with 15 studies available in 2023(N = 15 studies). The knowledge reported on the contributions or applications of each Digital Twin in healthcare, and its roles. The four main roles of digital twins in healthcare systems are health management and well-being promotion (n = 3), operational control (n = 12), information management (n = 5), and safety management (n = 4). The usage of digital twins in healthcare has the potential to stop unanticipated harm from occurring to patients while providing care. They may also be utilized to distinguish and manage the systemic concerns posed by crises. All stakeholders' access to real-time information and privacy are guaranteed by digital twins in the healthcare industry. Additionally, by enabling healthcare practices and fostering high levels of system efficiency by ensuring that healthcare facilities function properly and provide every patient with high-quality care, they help enhance self-care capacities.
Conclusion This assessment is focused on their contribution to the Digital Twin, which aims to enhance user experience in healthcare from a system engineering and human aspects perspective. This review explores and analyses opportunities for implementing digital twin technology in the Industrial Revolution 4.0 by considering various functionalities.

Keywords Digital twin · Healthcare · Safety · Health management

1 Introduction

The term digital twin refers to a graphical representation of an asset or object that is present at all times during its entire life cycle. With the use of real knowledge and a variety of facts, digital twins offer learning, reasoning, and dynamic recalibrating for better decision-making. They are intricate computer models that can be altered, updated, and changed in real time and are identical twins or exact replicas of the real world. Medical professionals may give patients advice on disease prevention and be prepared for medical emergencies using digital twin technology [1]. They can recognize the

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possibility of relapsing illnesses, such as cancer. The digital twin's prediction powers may help identify trends in fashion and alert people to unusual habits that could be harmful to their health. Professor Michael Grieves originally used the term "DT" to refer to product life cycle management in 2002. The National Aeronautics and Space Administration described it as an extensive multiscale, multiphysics simulation of a vehicle as-built that matches the life of the corresponding flying twin to forecast the life cycle of aviation in its early stages. Since then, the technology has developed and improved, making a larger range of applications possible and increasing its utility and accessibility [2]. Digital twins for those who are alive as well as dead can be created, and these algorithms can be customized for each patient by leveraging a range of heterogeneous data streams [3]. Digital twins incorporate big data, artificial intelligence (AI), and mathematical representations to predict the future and recognize possibilities. By 2024, it is anticipated that the market for health information technology will be worth $390.7 billion [4]. As shown in Fig. 1, the digital revolution and the rapid growth of massive quantities of data, cloud computing, and the Internet of Things (IoT) contributed to the exponential upgrading of the whole digital infrastructure. These elements worked together to produce an atmosphere that was more open to digital twin technology implementation than it had been when the idea was first proposed. Today, a digital twin is seen as a key component of the Industrial Revolution 4.0 in both the academic and industrial sectors [5]. Human health and healthcare services are now more important than ever before due to the COVID-19 pandemic process. Additionally, it is now more important than ever to make sure that working life can be sustained online and virtually. There have been several studies on digitalization conducted by governments, and organizations, and plans and arrangements are still in place. The pandemic process has placed the greatest demand on the necessity in the health sector [6]. Simultaneously, there have been instances where systems have been digitalized, enabling remote management of corporate operations and accelerating the development of new products and services [7]. It can be used in the healthcare industry like the engineering method. In the arena of health, predictive maintenance refers to ideas like anticipating and early

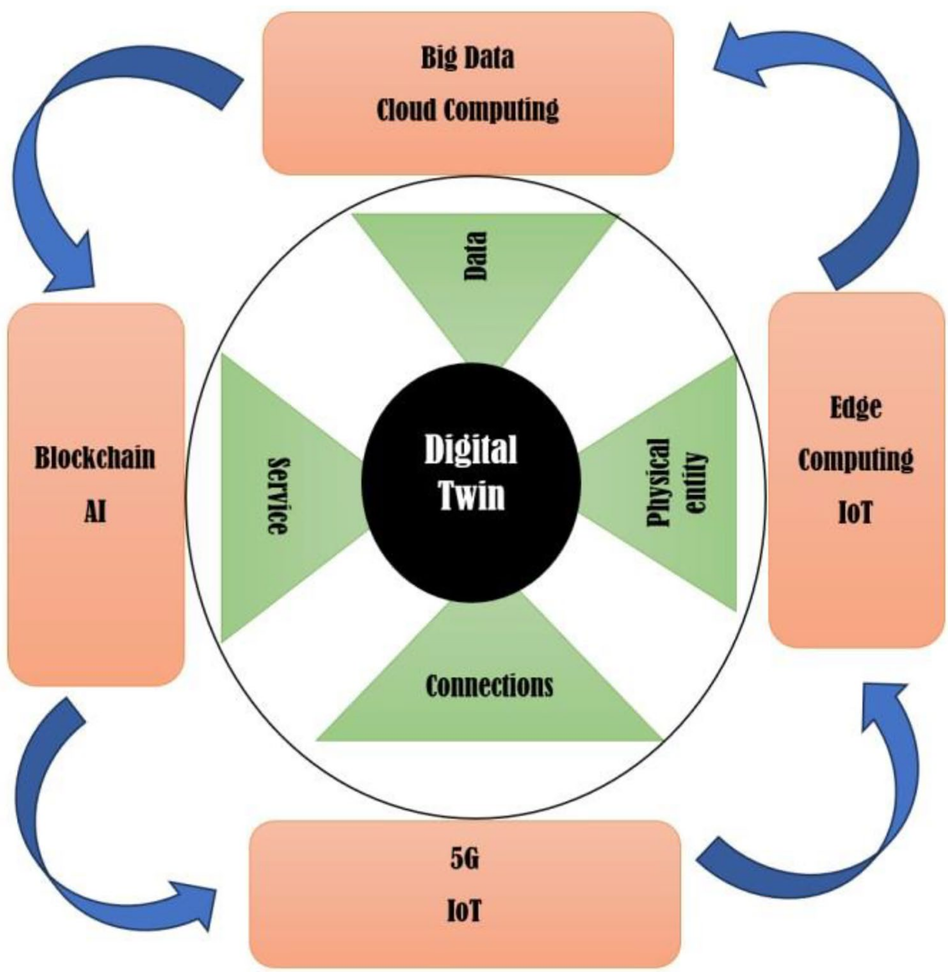

Fig. 1 Digital twin technologies in healthcare applications

disease detection through examination of the body's organs or symptoms. Engineering techniques like early failure predictions are included in predictive maintenance services. Organ transplants, replacing the lenses in cataract patients' eyes with new ones, and vascular bypass surgery to restore blood flow can all be categorized as engineering activities in the context of atherosclerosis in the medical profession [13]. The combination of three different technologies is the Digital Twin and it comprises AI, data, Machine Learning, and IoT. By combining Digital Twin and healthcare, it is possible to monitor, comprehend, and optimize each patient's activities, and gain insights for ongoing well-being and standard of living improvements. Additionally, with the use of AI in data processing, real-world and virtual settings can communicate more easily as a result of it [11]. Smart-linked hospitals have emerged as essential elements and independent ecosystems of Smart Cities with the introduction of the IoT within the industry 4.0 framework. One of the most difficult and quickly evolving IoT application areas is the healthcare sector. The medical profession has a history of being ahead of the curve and pursuing technical breakthroughs [16].

Healthcare systems are now able to find new information by using analytics over IoT data streams. Digital twin in Machine Learning (ML) and Big Data Analytics is used to analyze the behavior of real-time objects to virtually train the digital twin [18]. The review is based on the various types of technology that are used in Digital Twin and the need for Digital Twin in healthcare to analyze the treatment before and after and to improve the treatment methods. The digital twin technology has a wide range of capabilities, including modeling, simulating, and optimizing healthcare delivery, making it a valuable tool for improving patient care, advancing medical research, and driving innovation in the healthcare sector. We have explored the basic concept of digital twin technologies through a thorough review of relevant literature on the Scopus database and Google Scholar. The review process involved identifying papers that covered the use of Digital Twin in the healthcare domain. The selected papers include journal articles, research reports, scientific encyclopedias, and research papers. Emphasis was placed on research papers that not only define the Digital Twin concept but also examined its associated technologies within the healthcare field as shown in Fig. 1.

Section 2 of the study outlines the primary perspectives and definitions of Digital Twins as found in the literature. Section 3 details the study design and search strategy employed. Section 4 explains the various functions performed by digital twins and their corresponding use cases in the healthcare context. Section 5 discusses the current state-of-art in utilizing digital twin technology in the healthcare sector. Section 6 outlines the scope and future directions of digital twin technology. Section 7 provides concluding remarks.

2 Related works

Haleem et al. investigate the relationship between the requirement for healthcare and the digital twin, analyzing various features, technologies, and tools. To build visual models, digital twins use four technologies, including AI, cloud, extended reality, and IoT. They also gather, organize, and evaluate data to offer significant data. The specific tools used in Digital Twin for healthcare are AI and Cloud. Here, data from many sources are combined to create a special model for each patient, allowing doctors to make the appropriate plans. Cloud technology is used to collect the data from real-time patients and AI is used to run the data collected using algorithms for accurate prediction. The digital twin in healthcare plays a vital role in analyzing the person's data, assessing the symptoms, and providing accurate results using the algorithm [1]. Sun et al. analyze various dimensions using Digital Twin by combining AI, IoT, and big data which is utilized to create a detailed model of patients to make precise diagnoses and administer a customized course of treatment. The five components of the Digital Twin are the physical entity, virtual model, connections, Digital Twin data, and services. Technically, IoT supports the overall perception of the physical entity. AI is used for data analysis, data fusion, and the accuracy of many services. With the help of these Digital Twin features, precision medicine can be achieved by mapping patient data [2]. Ghatti et al. provide two types of application areas in digital twins namely digital twins in precision healthcare which creates the use of digital twins and patient-specific models for diagnostic and therapy planning in machine learning which is used for data generation and system modeling for disease prediction [3]. Croatti et al. represented the trauma leader, the shock room, the vital signs monitor, tools, and equipment to display real-time information about the trauma are all connected devices that flow information from connected devices that are connected during the operational phase of trauma management. Here, each digital twin is created as a micro-service that exposes an ad-hoc RESTful API to access the information and data it stores [4]. Barbiero et al. integrate mathematical modeling and AI approaches to provide a panoramic view of the pathophysiological situations. The renin-angiotensin procedure generates multi-tissue expression data for blood and lung on the expression of genes using the generative adversarial network (GAN), which serves as a proof of concept for transcriptomic integrability. The GAN model monitors and forecasts the clinically relevant endpoints that represent the evolution of the patient's vital parameters [5]. Hassani et al. connected two disparate interest groups and described how digital twin applications are being developed for the healthcare sector. This paper gives a better understanding medical applications of the digital twin and contributes to further improvement. This study examines current accomplishments, current problems, and potential issues to provide an overall current trajectory of digital twin implementations in support of healthcare [6]. Erol et al. advice that the digital twin is employed in the healthcare business for things like patient care, hospital operations, and the pharmaceutical industry. For operations and equipment, this technology produces incredibly effective outcomes. Although it involves more sophisticated and complex procedures, making a digital replica of the human body is analogous to producing technological items. Sensors can successfully communicate data to the digital twin of the produced thing as information from individuals is gathered through blood tests, imaging systems, and health scans, but they can be more costly and exhausting [7]. Bruynseels et al. proposed the philosophical and ethical ramifications of therapy for the enhancement of people employing digital twins, as well as proposed emergent data-driven healthcare practices. This suggests a data-driven strategy for healthcare has the potential to produce substantial positive societal impacts which also leads to segmentation and discrimination that ensures transparency of data usage, data privacy, and derived benefits [8]. Khan et al. explain how several technology platforms were combined to create digital twins, as well as the standards, reference models, and application of digital twins for medical treatment and intelligent production. The study examines the integration between digital twin models, financial constraints, and difficulty in execution [9]. Fagherazzi et al. describe the need for digital phenotyping on a large scale towards precision health by combining real data with digital data to identify the digital twin entering the era of patient [10]. Liu et al. proposed a virtual version of healthcare applicable to older individuals to address the issue of accurate emergency warnings. This is how the cloud-based digital twin clinical application technique connects various medical equipment and sensors. This essay principally aims to address the difficulty of combining and interacting with online environments. The novel idea for cloud-based healthcare is based on digital twins. The idea of digital twin healthcare (DTH) incorporates services like real-time monitoring of the elderly [11]. Kaul et al. provide a healthcare application that is used for diagnosis and treatment decision support. The integration of heterogeneous data coming from many sources might be made easier with the help of the digital twin and AI. The healthcare system offers improved diagnosis and higher-quality care, which can result in better clinical outcomes and more satisfaction among patients. These AI algorithms conduct cancer diagnosis and prognosis by taking into account a wide range of risk factors, which affect the patient's overall survival and the course of the disease [12]. Ahmadi et al. explore the aim of personalized medical treatment at the individual and healthcare provider levels. The desire for data-centric smart healthcare models that use technological innovation and AI enhances the patient's health and the ability to customize patient outcomes through focused medicinal treatments [13]. Strobel et al. design a taxonomy for digital twin applications in healthcare. The taxonomy is designed based on the seven steps of parameters and the design process which analyses the digital twin using the health recommendation. It helps in creating the designable dimensions and advancing the use of digital twins in healthcare assisting the practitioners based on the performance [14]. Elayan et al. provide a framework of useful contributions to the improvement of healthcare operations and digital healthcare. To identify heart abnormalities and diagnose heart disease, this research develops a classifier model for ECG heart rhythms using ML. This ECG classifier solution uses ML and AI along with several human body variables for regular evaluation and dissimilarity diagnosis [11]. Zhang et al. created an original neural network design to record simultaneous context interactions between liable terms, presenting a method for identifying potentially vulnerable functions to support healthcare digital twins. The method outperforms state-of-the-art Deep Learning-based methods to enable the efficient understanding of potentially highly susceptible code layouts [12]. Benedictis et al. discuss four major categories namely Digital twins are used in the treatment of patients, training and practice of medical professionals, the pharmaceutical sector, and the oversight of public health. Can Twin is being implemented in the context of the COVID-19 pandemic to build up individuals' movement and assess isolation from society [15].

Kolekar et al. present a web-service platform for merged personalized medicine that is based on digital twins and used in hospital activities. This is based on the specifications where the services will forecast and assess the precision of the displayed result. The AI is used to determine whether the concept is practical, and it is then simply developed to add extra benefits [16]. Lakhan et al. presented a safe, resilient, and smart sensors-aware wearable technology. The effort and finances required to manage healthcare sensor data for security, job execution, and fault tolerance to the Industrial Internet of Things (IIoT), which is based on federated digital twin fog-cloud topologies. The SFTS algorithm is a secure and fault-tolerant scheme used in this study that executes medical records with the least amount of offloading and processing latency while optimizing data from IoT sensors [17]. Wang et al. did a thorough analysis of the literature on the intersection of cloud computing, IoT, healthcare, and digital twins. The efficient operation of digital twins in the healthcare industry is made possible by these technologies. It works by utilizing modern cloud computing apps and digital twin software to give healthcare professionals improved patient outcomes in real time [18]. Kim et al. proposed therapeutic choices in the prostate cancer (PCa) approach to forecast disease diagnosis, through statistical analysis and

ML, the digital twin technique here facilitates interoperability between the world and simulations. Utilizing the reverse connecting technique, the PCa process and machine learning were merged which is used to predict BCR and this process is suitable for the application of CDSSs using the ML approach [19]. Shi et al. demonstrate an AR technology for surgical puncture guidance during thermal ablation of liver cancers. Here, the digital twin idea is applied to estimate inner heterogeneity movement in real-time, namely spontaneous respiration, and to analyze puncture navigation more precisely. The estimated preoperative data was used to make, OST-HMD calibration and image-patient identification to determine the impact of the procedure being performed in the puncture experiment [20]. Mourtzis et al. provide an AI-based platform for identifying cancer in human beings. The information is gathered using Cloud Database which is used to create a user profile and also can examine the patient's past information. The analysis procedure makes use of the GUIs tool, which also makes it easier to organize the data and store it in the cloud database. Patients are categorized using artificial neural networks, while MRI scans are analyzed using convolutional neural networks. This approach aims to do a step-by-step analysis of data for medical decisions aiming for better outcomes [21]. Abirami et al. proposed a patient-centered screening at a distance that can be made using a digital twin-based healthcare system (DTHS) with intelligent internet-based medical facilities. This work in DTHS also creates a cloud platform for Parkinson's disease prediction utilizing an optimized fuzzy-based k-nearest Neighbor method that takes into account prediction speed, prediction accuracy, F1-Score, and Matthew's correlation coefficient [22]. Sarp et al. designed and implemented a novel AI-based model that might anticipate the development of wound rehabilitation and identify non-healing injuries a digital twin-based chronic wound care framework was created. This model employs tissue segmentation, which enables simple, quick, and accurate implementation without the need for preprocessing, to compare images of chronic wounds before and after four weeks of treatment. This telemedicine application employing the digital twin idea offers beneficial insights into the involvement of patients in the healing process [23]. Han et al. capture the importance of collecting and analyzing data about physical entities within hospital operations, which cannot be overstated. This data is crucial for making informed decisions. However, there is still a noticeable gap in the availability of effective strategies for integrating real-time data from diverse sources. This integration is necessary to enhance both clinical and non-clinical processes in healthcare environments and to address this gap, a conceptual framework is implemented in digital twinning within smart hospitals. This framework builds on previous investigations into digital twins, which enable real-time feedback from physical entities [24].

Ankush et al. emerged with the overarching goal of enhancing patient life expectancy while concurrently reducing healthcare costs. Among these, Digital Twin stands out as an up-and-coming and transformative technology in the healthcare domain. Development of a sophisticated smart context-aware physical activity monitoring framework, amalgamating advanced techniques [25]. Lee et al. introduce a non-contact robotic diagnostic system tailored for otolaryngology clinics integrating a flexible endoscope manipulation robot and a parallel robot arm for the control of additional medical instruments. An innovative 4 degrees of freedom (DOF) control mechanism is employed, enhancing the efficiency of the single robotic arm in managing the endoscope as compared to traditional two-handed approaches [26]. Vats et al. predict cardiovascular disease at an early stage, thereby contributing to the extension of life expectancy and also a meticulous examination of the patient health records, emphasizing the identification of significant features [27]. Kumari et al. build a bridge to the virtual medical world for enabling diagnosing, monitoring, and also predicting the future for enhanced medical services. A blockchain-assisted certificateless public auditing mechanism for cloud-based digital twin healthcare network for data integrity in cloud storage [28]. Ziani et al. applied continuous wavelet transforms on an ECG signal that contains the electrical activities of both the fetal and maternal heart, leading to the emergence of a complex energy domain that encompasses separate energy sub-domains [29]. Ziani et al. have designed an intelligent machine that utilizes the AlexNet Deep Neural Network Architecture to classify time-scale images and evaluate the quality of estimated sources or extracted signals [30]. Ziani et al. have developed a method for detecting fetal electrocardiogram (FECG) signals using a single-channel abdominal lead. They combine Convolutional Neural Network (CNN) with advanced mathematical techniques including Independent Component Analysis (ICA), Singular Value Decomposition (SVD), and Nonnegative Matrix Factorization (NMF) to perform dimension reduction [31].

3 Methods

3.1 Study design

A quick survey of studies concerning the use of digital twin technology in advancing the health sector. This review provides standard systematic reviews rather than decision-making information. An expanded collection of examinations, a detailed examination of the study quality, or reports of insights from earlier research using a streamlined approach to the verification process are often not included. Our protocol was approved with the open science framework in 2018, and the main objective of this evaluation was to find ways that Digital Twin may promote the advancement of healthcare. We compiled the analysis of recent works on digital twins and the challenges in creating, utilizing, and implementing them. There were 6 years worth of publications taken into account from 2018 to 2023. The emergence and adoption of technologies often follow a trajectory influenced by various factors such as technological advancements, industry needs, regulatory changes, and societal acceptance. In the case of digital twin technology in healthcare, there are several reasons why its significant growth and recognition started around 2018, even though the concept of a digital twin has been around since 2002. The points that could be used to justify choosing 2018 as a starting point and also to give a clear thought for drawbacks for analyzing digital twin technology in healthcare:

(A) **Technological Advancements:**
While the concept of digital twins existed, advancements in computing power, connectivity, and data analytics around 2018 might have reached a point where the implementation of digital twin in healthcare became more feasible and practical.

(B) **Healthcare Industry Readiness:**
The healthcare industry is known for its complex regulatory landscape and cautious approach to adopting new technologies. It could be argued that by 2018, the industry had reached a stage where it was more open to embracing innovative technologies like digital twin due to increased awareness, understanding, and technological maturity.

(C) **IoT and Sensor Integration:**
The Internet of Things (IoT) and the integration of various sensors in healthcare devices and systems have become more prevalent around 2018. This integration is crucial for creating comprehensive digital twins that accurately represent the physical entities in the healthcare ecosystem.

(D) **Data Security and Privacy Measures:**
Data security and privacy concerns are especially high in the healthcare sector. It's possible that by 2018, there will be more robust measures and frameworks in place to address these concerns, making stakeholders more willing to explore digital twin technology.

(E) **Clinical Research and Evidence:**
The years leading up to 2018 might have seen an increasing body of clinical research and evidence supporting the effectiveness and benefits of digital twin applications in healthcare, leading to greater acceptance and adoption by healthcare professionals.

(F) **Market Forces and Industry Trends:**
Sometimes, the adoption of a technology is also influenced by market forces and industry trends. If key players, startups, or technology providers started focusing on digital twin solutions for healthcare around 2018, it could have spurred interest and investment in the field.

The technology gained momentum and became more practically applicable and accepted in the healthcare sector.

The application of the digital twin approach in healthcare is expected to have a significant impact on the advancement of technology as shown in Fig. 1. The development in technology has enabled the creation of digital copies of people, healthcare systems, and medical equipment. The primary objectives of this technology are to monitor, analyze, and predict issues related to personalized care delivery, predictive maintenance for healthcare facilities, and the reduction of research and development costs. The digital twin technology can simulate various patient characteristics, replicating their behavior and response in specific situations, thereby aiding in health tracking, disease diagnosis, and the planning of preventive treatments. Additionally, it provides representative insights into a broader population through simulation-derived data. Healthcare professionals can utilize digital twin to study infected patient data for future research, conducting treatment simulations and identifying promising paths.

3.2 Search strategy

"Digital twin" and "healthcare" are used as keywords for searching in the peer-reviewed journals Web of Science, PubMed, IEEE Xplore, Scopus, and ScienceDirect. Journal and conference articles that discuss Digital Twin's uses in healthcare are included in the study. Excluding articles and papers that outline a scheme to help that is not subject to peer review, a healthcare organization, and research published in concise statements and outlines that do not report the effects of the digital twin through empirical investigations and techniques. The review paper encompasses diverse healthcare aspects that play a crucial role in digital twin technology, examining existing techniques for analyzing the impact of digital twins in healthcare. Exclusion criteria for the review paper pertain to schemes lacking peer review, healthcare organizations, and concise statements or outlines in research publications that do not present empirical investigations or techniques demonstrating the effects of digital twins. Studies are discussed based on the existing technologies that are used in Digital Twin in healthcare and the ways to improve healthcare management and the betterment of treatment in Fig. 2.

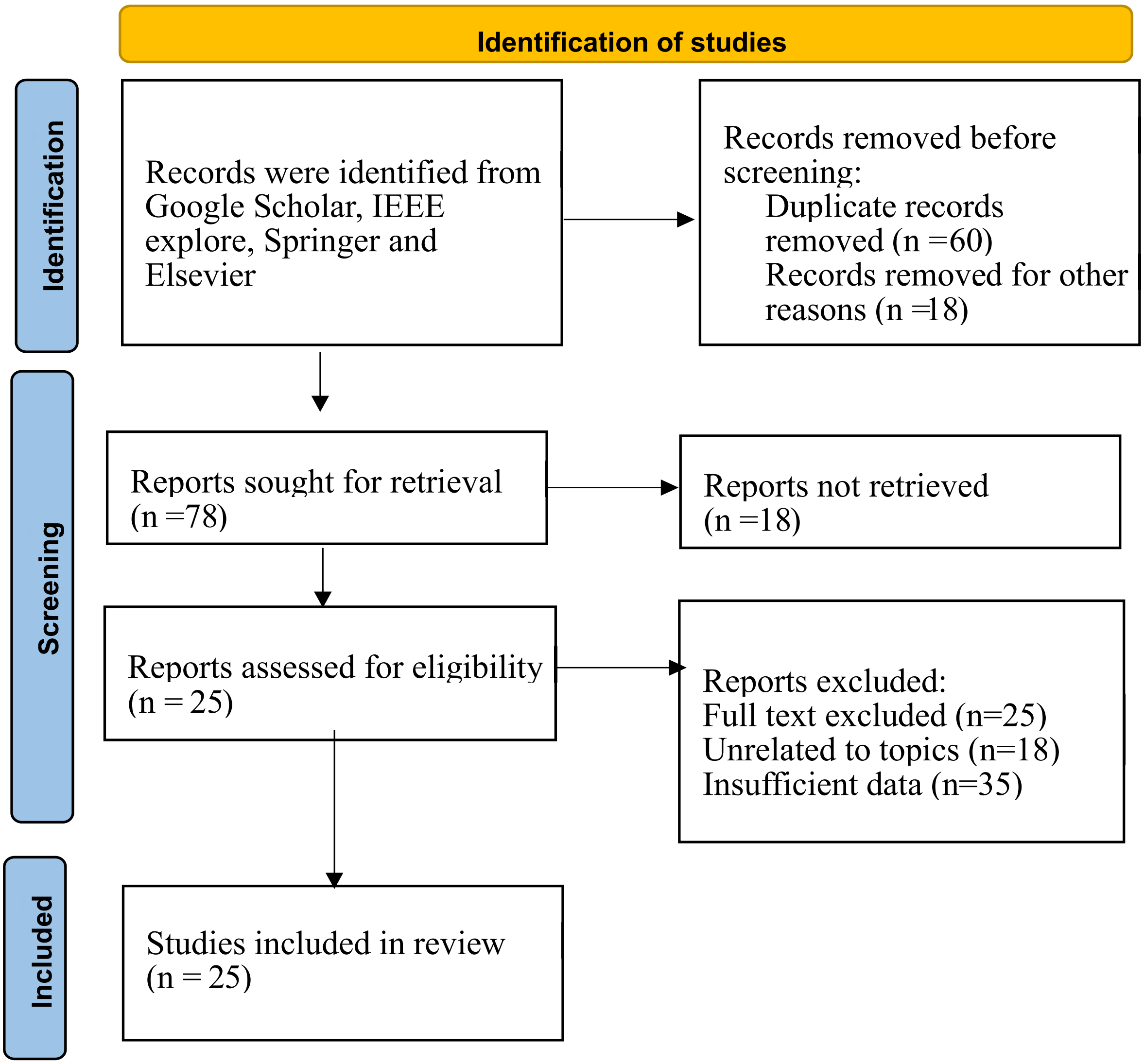

Fig. 2 Flowchart for study selection

4 Functions of digital twin

The technology involved in Digital Twin is operational control, health management and well-being promotion, safety management, and information management. Figure 1 shows a comparison of all these technologies and their key findings are given below.

4.1 Operational control

Providing every patient with high-quality care which results by making certain that healthcare facilities are efficient and have an excellent system performance level that can be attained is briefly explained below in Table 1. This review for operational control is performed for two types of Digital Twin namely Process, System in which Digital Twin plays an important role by giving reliable diagnosis for prediction of treatment.

4.2 Health management and well-being promotion

Health management strategies should be enabled to enhance self-care characteristics. This function discovers Digital Twin by combining various technologies by modifying the disease management and prevention of digital phenotyping patterns elaborated below in Table 2. Only three articles are available in the literature to elaborate on health management.

Table 1 Key findings of digital twin in operational control

Authors	Type of Digital Twin	Key findings
Haleem et al.	Process	Embedded sensor and IoT device data are collected, analyzed, and visualized using a model that makes use of visualization techniques. Patient treatment is significantly improved with Digital Twin.
Sun et al.	Process	By fusing AI, Big Data, and IoT, we may create an all-encompassing virtual model of the human organs that can be used for reliable diagnosis, current–time monitoring of complicated diseases, and treatment impact prediction.
Ghatti et al.	System	To fully utilize the possibilities of digital twins for health care, pandemic response, hospital/clinic treatment, and targeted medical services will be aided.
Croatti et al.	Process	A digital twin is viewed as a tangible possession that is mirrored by two digital twins, where the trauma occurs. The care of severe trauma is supported and digitalized via digital twin.
Hassani et al.	Process	IoT as a business idea and digitization as a service structure are employed for healthcare services as well as an actual resource for unambiguous comparison to the digital twin in medicine.
Bruynseels et al.	System	Using sophisticated information on people's molecular appearance, physiology, way of life, and dietary preferences, the digital twin idea analyses healthcare and human enhancement.
Kaul et al.	System	When analyzing the growth of the disease and predicting outcomes for clients with cancer, a digital twin and AI are utilized to assist in more rapid and precise clinical choices.
Assalemi et al.	System	Digital twin to achieve precision healthcare, cyber security challenges, and ethical implications for emergency paradigms.
Strobel et al.	System	Contribution to organizing the body of knowledge on designing digital twins in healthcare which enables innovation the digital twin applications.
Wang et al.	System	To create a workable Digital Twin preserving strategy for essential health services, a variety of supporting technologies, including cloud-based services, information transfer protocols, and storage space file formats, were used.
Kim et al.	System	In the Digital Twin framework, the pathogenic condition and BCR should be predicted in those diagnosed with prostate cancer to optimize medical procedures, increase wellness, and lower expenses for healthcare and issues.
Chi et al.	System	OST-HMD information is all included in the enhanced imaging workflow of the digital twin enabling easy operative navigating.

4.3 Safety management

Prevention of accidental or unforeseen injury to patients while performing health care procedures; spotting threats to a system that are tied to crises and assisting in controlling the effects are explained in Table 3. The authors discussed solutions for myocardial irregularities and circulatory conditions for the administration of healthcare facilities.

4.4 Information management

Accessibility to real-time information for stakeholders while maintaining their privacy and security is specified in Table 4. This review on information management is based on five articles on the creation of Digital twins and support of the technologies involved in patient diagnosis.

Table 2 Key findings of digital twin in health and well-being promotion

Authors	Type of Digital Twin	Key findings
Barbiero et al.	Product	By merging data from GNNs and GANs at the system, cells, and molecular levels, two therapeutic instances were analyzed to provide an overall picture of the ailments of those being studied. A synthesis-AI interaction that makes use of accessibility evaluation to pinpoint restrictions on the health and medical situation of the system field.
Fagherazzi et al.	Product	To discover the digital twin, combine hospital records with actual technological information and modify disease management and prevention which provides both digital phenotyping patterns and uniform manifold approximation and projection.
Liu et al.	Product	Portable wellness products that are digitally linked enable interactivity and fusion between real-world and virtual healthcare environments, enhancing CloudDTH ability to monitor older people's health.

Table 3 Key findings of digital twin in safety management

Authors	Type of Digital Twin	Key findings
Erol et al.	System	By speeding up the procedures of vaccination and drug development that take place using COVID-19, a digital twin is utilized to address issues in the administration of healthcare facilities and medical expenditures.
Elayan et al.	System	The virtual twin structure can aid in the identification of myocardial irregularities and circulatory conditions with the aid of an electrocardiogram (ECG) heart rhythms classifier model and machine learning.
Benedictis et al.	System	In contemporary medical facilities, digital twin technology is built on the virtualization of physical assets and the bilateral connectivity between both virtual and real spaces.
Mourtzis et al.	System	Implementation of Digital Twin utilizes predictive analytics by gathering data for Cloud Database's organized approach to the diagnosing procedure and MRI scan illustrations.

5 Discussion

5.1 State of the art of digital twin usage in healthcare

Despite rapid growth and development in activation technologies, the applications of digital twins show increasing promise to deliver precise diagnostics and simulation velocity reserve for patient-oriented modeling. The main objective of using digital twin technology in healthcare is to enhance patient care, improve operational efficiency, and facilitate innovation in medical practices. The purpose of using digital twin technology in healthcare includes personalized medicine which creates a detailed and dynamic model of an individual patient to tailor treatment plans and interventions based on specific characteristics. Analysis of data is done by predictive analytics and early intervention. The safety and efficacy before actual deployment are done using the simulation of medical devices. The operations are optimized for hospital management using a digital twin model. Healthcare professionals also use digital twins for training purposes. The use of technological advances in conjunction with interdisciplinary, Multiphysics, and multiscale models to deliver durable, specific, and successful treatments is known as the digital twin in the field of healthcare. This method is used to precisely identify a patient's cause, define the treatment target, and administer a customized course of action. Various algorithms used in Digital Twin are analyzed below in Table 5.

5.2 Operational control

To lessen and mitigate the consequences and delays that feature to understand and optimize the business process within the field of medicine. In this situation, operational control may help the hospitals and clinics run with greater effectiveness. Digital Twin focuses on enhancing the medical process and improving the clinical process by replicating rehabilitation facilities or clinics which enhances productivity while posing fewer opportunities. There are many functions, ranging from monitoring the flow of patients to forecasting the lack of resources. To observe technological advances in the

Table 4 Key findings of digital twin in information management

Authors	Type of Digital Twin	Key findings
Khan et al.	System	The incorporation of many supporting technologies for the creation of a digital twin and the establishment of underlying concepts, and norms, regards mathematical models, and study in innovative manufacturing and medical care.
Zhang et al.	System	An innovative complete cyber resilience approach is developed to identify unsecured functionality in software development for healthcare virtual twins, and a deep code method is designed to explore contextual code linkages among vulnerability-related phrases.
Kolekar et al.	Product	For medical organization connections, a digital twin-based absorbed personalized healthcare web-service platform ensures platform autonomy based on the forecasted criteria.
Lakhan et al.	Product	Creating virtualized representations of hosts that enhance embedded sensor data and execute it with the least amount of dumping and computational delays, IIoHT frameworks based on digital twin collaboratively learning allowed fog-cloud topologies to be used.
Abirami et al.	System	A conceptual electronic wellness-based digital twin-based healthcare system (DTHS) facility to improve the effectiveness related to illness prognosis and patient-oriented assessment processes from distant locations. The DTHS is created for those with Parkinson's using a cloud-based platform.

Table 5 Comparative analysis of various algorithms used in digital twin

Author	Digital Twin Technology Used	Dataset	Algorithms	Accuracy	Result
Kim et al.	Prostate Cancer process with Machine learning	Cloud Data warehouse (CDW)	(a)Logistics Regression (LR) (b)Bayesian Network (BN) (c)Support Vector Machine (SVM) (d)Random Forest (RF) (e)Neural Network (NN) (f)Recurrent Neural Network (RNN) (g)Long Short-Term Memory (LSTM)	(a) 77.1 (b) 75.3 (c) 76.4 (d) 72.6 (e) 79.9 (f) 47.4 (g) 77.0	To improve wellness and save healthcare costs, the medical profession adopted the digital twin architecture.
Shi et al.	Liver tumor with Holographic Augmented Reality	4-D-CT scanner	Generalized moving least-square algorithm	79.9	Possibility of using an intuitive navigational paradigm to resolve the healthcare challenge of percutaneous puncture
Mourtzis et al.	AI and Augmented Reality	PET scan	AI	75.4	To improve the diagnostic ability and make the prognosis more accurate
Abirami et al.	Parkinson's Illness and the Digital Twin Healthcare Framework	Real-time voice sample	Support Vector Machine (SVM) classifier	97.95	Using characteristics of speech derived from distant clients, prognosis-based informal parameters may help to monitor patients remotely and give treatment recommendations.
Sarp et al.	Digital twin with Wound Healing	CIFAR-10	AI	97	Provides valuable insights for the participating patients and families.

digital twin of a medical center, participants conducted a digital anxiety test using the Digital Twin technology by examining organizational ability.

The review identifies an extensive effort (12 out of 25 studies) to support operational control consisting of digital twin systems and processes for performance control. Continuous evaluation and accurate diagnosis of complicated disorders using a comprehensive digital twin of human organs by combining data, IoT, and AI are used to select appropriate treatment plans and for the prediction of treatment effects. Data is gathered from IoT devices coupled with sensors and analyzed using machine learning and IoT devices can now be displayed using an algorithm that makes use of visualization instruments. IoT is employed as an operating template for medical services and is also an intangible resource for unambiguous references of digital twins in healthcare. Here digital twin is considered a physical asset for supporting trauma management. When Digital twin is combined with AI it supports faster and more accurate clinical decisions in providing important scenario simulation for the prediction of cancer patients. In addition to providing psychological augmentation, the digital twin concept also uses precise information on people's lifestyles. The digital twin is used to achieve precision healthcare, cyber security challenges, and ethical implications for emergencies. To predict prostate cancer a Digital Twin framework is used to predict cancer progression in patients as well as BCR to improve the medical process promote health and reduce medical costs. Digital twin with data collection, cross-platform transmission, and Multiview OST-HMD calibration enables easy surgical navigation.

5.3 Health management and well-being promotion

The development of these innovations is intended to enhance the way of living in individuals. To maintain good health and a healthier lifestyle controlling healthcare costs should be done through digital health interventions—the promotion of a healthier lifestyle is considered to be easily accessed. Combining the real-world data with the clinical data is done to identify the digital twin and also to modify disease management by providing both digital phenotyping and manifold projection. The personal health management of elderly patients CloudDTH is used for interaction and convergence between the patients to achieve a Digitally Twinned wearable medical device.

5.4 Safety management

The purpose of safety management is to reduce unfavorable outcomes or injuries caused by healthcare procedures. Treatment of patients' mistakes and difficulties frequently leads to inadequate systems. Investigating the possibility of an emergency requires the use of digital twin technologies in safeguarding patients. Implementation of digital twin utilizing predictive analysis by gathering data for MRI scan images and the subsequent evaluation procedure for diagnosis purposes. Digital Twin framework is used for beneficial contribution to digital healthcare using the ECG heart rhythm classifier model.

5.5 Information management

To provide high-quality patient care, it is necessary to analyze and secure both digital and tangible medical records. These tasks present numerous obstacles, including concerns about patient privacy and data volume. Recent years have seen a tremendous expansion of the medical records management tool which is now being utilized to identify significant medical developments and deliver prompt preventive services. Real-world patient-specific healthcare data is collected and represented using Digital Twin. Digital Twin in healthcare helps to recognize the vulnerable functions for cyber resilience and a deep code technique is performed. A web-service platform for hospital organizations based on Digital Twin is performed to ensure platform independence on prognostic requirements.

Digital Twin technologies used in various studies have been shown in Fig. 3. Kim et al. proposed a Prostate Cancer process using Machine learning, AI, and Blockchain. Shi et al. analyze the Liver Tumor with Holographic Augmented Reality, AI, and IOT. Mourtzis et al. propose Diagnostic methods using AI and Augmented reality. Abirami et al. monitored the Digital twin of Parkinson's disease using IoT, Machine Learning, Big Data Analytics, and the Cloud. Sarp et al. provide an insight for Wound Healing using IoT, AI, and Blockchain. The technologies used by the Digital Twin cover 26.7% of AI, 20.0% of IOT, 13.3% of ML, Blockchain, and AR, and 6.7% of cloud and BDA. Here the AI is used to collect the data and validate the collected data, the validated data is stored using Blockchain, and the stored data

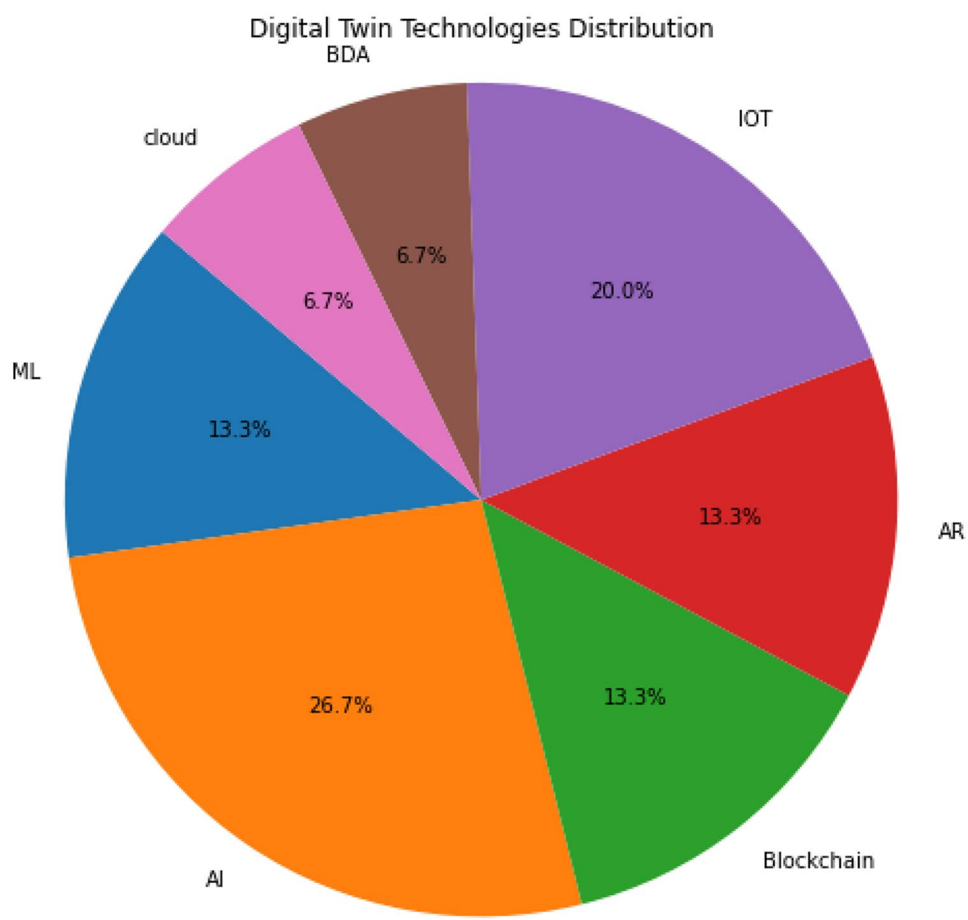

Fig. 3 Ecosystem of technologies in digital twin implementation

is processed using a Cloud platform to provide scalability, flexibility, and computational power, IOT and the ML read these data analyzes the data. This review gives the analysis of treatment results for good treatment recommendations.

6 Future direction and scope of digital twin technique

Utilizing digital twin technology, actual events are simulated, predicted, and improved. Patients would have an environment-friendly screening choice; healthcare providers would have safer and more effective tracking techniques. AI is used to improve the speed, precision, and effectiveness of human efforts and is also used to identify manually intense data management tasks. The data is collected and validated by AI and the collected data is stored in Blockchain. Nowadays, the twinning of technologies is more hybridized. However, digital twinning faces numerous problems that threaten its expansion by handling private and sensitive information including networked devices that are a prime target for hacks. Because of this, governments and policymakers must combine the legal and regulatory aspects to create data-sharing protocols that are more secure. Since information serves as the foundation of Digital Twins, methods for quality assurance must also be implemented in real tangible structures to mix the data with the replicated processes (twins) and guarantee good Digital Twin mode functioning. Future productivity enhancements will be made possible by the employment of digital twin technology, which also lowers risk in a variety of contexts, including those involving actual entities, data, and virtual models, as well as the most complicated situations in an artificial setting. Analyzing the physical and the real-time images with the Digital Twin technology and improving the treatment recommendation can be done. In the future, however has several limitations, including the use of primarily provided data that might establish the baseline and change over time. This quick analysis demonstrates that the emerging topic of digital twins in healthcare has significant promise during the COVID-19 pandemic. The limitations of the digital twin in healthcare include the widespread adoption of digital twin technologies in routine clinical practice, hindering the improvement of clinical procedures and patient care in healthcare facilities. A significant challenge in the digital twin healthcare industry is safeguarding patient data from unauthorized access and cyber threats, which requires establishing robust data security plans to comply with privacy laws ensuring the secure handling of private medical information. Also, the digital twin technology in healthcare comes with the deployment in healthcare organizations to determine if the benefits justify the costs. Therefore, interdisciplinary teams from a variety of fields, such as digital health, data science, human ergonomics, and human–computer interactions, should look into the technology's potential and tackle any issues that might affect how it is designed for use in healthcare.

7 Conclusions

Digital Twin is a key component of the Industrial Revolution 4.0 in both academic and industrial sectors. Human health and healthcare services are more important nowadays due to the pandemic process to make sure working life can be sustained online and virtually. Digital Twin has a lot of potential development in the future, especially in healthcare aspects. In this paper, we have carried out a detailed analysis of the incorporation of the Digital Twin technique in health by analyzing functions and parameters involved in its implementation in real-time scenarios. Further to this, we have performed an analysis of the safety and operational control of Digital twin technology in hospitals. In the future, Digital Twin will help develop patient-specific architecture models in personalized medicine.

Author's contribution Dr. Suchetha M had full access to all of the data in the study and took responsibility for the integrity of the data and the accuracy of the data analysis. Concept and design: Dr. Suchetha M. Acquisition, analysis, or interpretation of data: Preethi S. Drafting of the manuscript and clinical validation: Rajiv Raman. Critical revision of the manuscript for important intellectual content: Kalyana Chakravarthy Veluvolu Supervision: Dr. Suchetha M.

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Declarations

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Code availability Not applicable.

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Consent to publish Not applicable.

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References

1. Haleem A, Javaid M, Singh RP, Suman R. Exploring the revolution in healthcare systems through the applications of digital twin technology. Biomedical Technology. 2023;4:28–38.
2. Sun T, He X, Song X, Shu L, Li Z. The digital twin in medicine: a key to the future of healthcare. Front Med. 2022;9:907066.
3. Ghatti S, Yurish LA, Shen H, Rheuban K, Enfield KB, et al. A Survey of Current Methods. Archives of Clinical and Biomedical Research. 2023;7(2023):365–81.
4. Croatti A, Gabellini M, Montagna S, Ricci A. On the integration of agents and digital twins in healthcare. J Med Syst. 2020;44:1–8.

5. Barbiero P, Vinas Torne R, Lió P. Graph representation forecasting of patient's medical conditions: Toward a digital twin. Front Genet. 2021;12:652907.
6. Hassani H, Huang X, MacFeely S. Impactful digital twin in the healthcare revolution. Big Data and Cognitive Computing. 2022;6(3):83.
7. Erol T, Mendi AF, Doğan D. The digital twin revolution in healthcare. In: 2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT). IEEE; 2020. p. 1–7.
8. Bruynseels K, Santoni de Sio F, Van den Hoven J. Digital twins in health care: ethical implications of an emerging engineering paradigm. Front Genet. 2018;9:31.
9. Khan S, Arslan T, Ratnarajah T. Digital twin perspective of fourth industrial and healthcare revolution. Ieee Access. 2022;10:25732–54.
10. Fagherazzi G. Deep digital phenotyping and digital twins for precision health: time to dig deeper. J Med Internet Res. 2020;22(3):e16770.
11. Liu Y, Zhang L, Yang Y, Zhou L, Ren L, Wang F, Deen MJ. A novel cloud-based framework for elderly healthcare services using digital twin. IEEE Access. 2019;7:49088–101.
12. Kaul R, Ossai C, Forkan ARM, Jayaraman PP, Zelcer J, Vaughan S, Wickramasinghe N. The role of AI for developing digital twins in healthcare: The case of cancer care. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 2023;13(1):e1480.
13. Ahmadi-Assalemi G, Al-Khateeb H, Maple C, Epiphaniou G, Alhaboby ZA, Alkaabi S, Alhaboby D. Digital twins for precision healthcare. Cyber defence in the age of AI, Smart societies and augmented humanity. 2020;133–58.
14. Strobel G, Möller F, van der Valk H. Healthcare in the era of digital twins: towards a domain-specific taxonomy. Tech Rep. 2022.
15. De Benedictis A, Mazzocca N, Somma A, Strigaro C. Digital Twins in Healthcare: an architectural proposal and its application in a social distancing case study. IEEE J Biomed Health Inform. 2022.
16. Kolekar SS, Chen H, Kim K. Design of Precision Medicine Web-service Platform Towards Health Care Digital Twin. In 2023 Fourteenth International Conference on Ubiquitous and Future Networks (ICUFN) (pp. 843-848). IEEE; 2023.
17. Elayan H, Aloqaily M, Guizani M. Digital twin for intelligent context-aware IoT healthcare systems. IEEE Internet Things J. 2021;8(23):16749–57.
18. Zhang J, Li L, Lin G, Fang D, Tai Y, Huang J. Cyber resilience in healthcare digital twin on lung cancer. IEEE Access. 2020;8:201900–13.
19. Kim JK, Lee SJ, Hong SH, Choi IY. Machine-learning-based digital twin system for predicting the progression of prostate cancer. Appl Sci 2022;12(16):8156.
20. Kolekar SS, Chen H, Kim K. Design of precision medicine web-service platform towards health care digital twin. In: 2023 Fourteenth International Conference on Ubiquitous and Future Networks. IEEE; 2023. p. 843–8.
21. Mourtzis D, Angelopoulos J, Panopoulos N, Kardamakis D. A smart IoT platform for oncology patient diagnosis based on ai: Towards the human digital twin. Procedia CIRP. 2021;104:1686–91.
22. Abirami L, Karthikeyan J. Digital twin-based Healthcare System (DTHS) for Earlier Parkinson Disease Identification and Diagnosis using Optimized Fuzzy based k-Nearest Neighbor Classifier Model. IEEE Access. 2023.
23. Kim JK, Lee SJ, Hong SH, Choi IY. Machine-learning-based digital twin system for predicting the progression of prostate cancer. Appl Sci. 2022;12(16):8156.
24. Han Y, Li Y, Li Y, Yang B, Cao L. Digital twinning for smart hospital operations: Framework and proof of concept. Technol Soc. 2023;74: 102317.
25. Manocha A, Afaq Y, Bhatia M. Digital Twin-assisted Blockchain-inspired irregular event analysis for eldercare. Knowl-Based Syst. 2023;260: 110138.
26. Lee SH, Lee DW, Song HS, Jeong S, Ji Y, Song JS, Yi BJ. Robotic manipulation system design and control for non-contact remote diagnosis in otolaryngology: digital twin approach. IEEE Access. 2023;11:28735–750.
27. Chen J, Wang W, Fang B, Liu Y, Yu K, Leung VC, Hu X. Digital twin-empowered wireless healthcare monitoring for the smart home. IEEE J Sel Areas Commun. 2023.
28. Kumari D, Kumar P, Prajapat S. A blockchain-assisted public auditing scheme for cloud-based digital twin healthcare services. Clust Comput. 2023;1–17.
29. Ziani S. Enhancing fetal electrocardiogram classification: A hybrid approach incorporating multimodal data fusion and advanced deep learning models. Multimed Tools Appl. 2023;1–41. https://doi.org/10.1007/s11042-023-17305-6.
30. Ziani S, Manikandan S, Rizal A. Time-scale image analysis for detection of fetal electrocardiogram. Multimedia Tools and Applications. 2023;83:1–23. https://doi.org/10.1007/s11042-023-17165-0.
31. Ziani S, Farhaoui Y, Moutaib M. Extraction of Fetal Electrocardiogram by Combining Deep Learning and SVD-ICA-NMF Methods. Big Data Mining and Analytics. 2023;6(3):301–10.