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A COMPREHENSIVE REVIEW OF DIGITAL TWIN TECHNOLOGY APPLICATIONS IN HEALTHCARE

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Abstract:
Digital twin technology defined as the creation of a virtual replica of a physical entity or system, is rapidly gaining traction in healthcare as a tool for enhancing patient care, operational efficiency and medical research. By continuously integrating real-time data from sensors, medical devices and electronic health records, digital twins enable dynamic simulations that mirror the health status of individuals or the functioning of clinical environments. This capability allows clinicians to test treatment strategies virtually, predict disease progression and personalize interventions without exposing patients to unnecessary risk. This review article explores the evolution of digital twin applications in healthcare, ranging from patient-specific models for precision medicine and surgical planning to system-level twins that optimize hospital resource allocation and workflow management. The discussion emphasizes how digital twins can support chronic disease management, rehabilitation and preventive care by providing predictive insights and adaptive treatment pathways. In addition, the article examines the integration of artificial intelligence, machine learning and Internet of Things (IoT) technologies as enablers of robust digital twin ecosystems. Despite their promise, several challenges hinder widespread adoption. Key concerns include ensuring data security and patient privacy, achieving interoperability across diverse healthcare platforms, addressing computational demands and navigating ethical and regulatory frameworks. The review highlights ongoing research efforts and collaborative initiatives aimed at overcoming these barriers. Ultimately, digital twin technology represents a paradigm shift in healthcare delivery, with the potential to transform clinical decision-making, reduce costs and improve patient outcomes. However, realizing this vision will require sustained interdisciplinary collaboration among healthcare providers, technologists, policymakers and ethicists.
Key words: **Digital Twin Technology, Healthcare Innovation, Personalized Medicine, Precision Medicines, Medical Equipment Management**

1. INTRODUCTION

The rapid advancement of digital technologies has significantly transformed the healthcare sector, enabling more precise, predictive and personalized approaches to patient care. Among these emerging technologies digital twin technology has gained considerable attention for its potential to revolutionize healthcare delivery and clinical decision-making. A digital twin is a virtual replica of a physical entity, system or process that is continuously updated using real-time data, allowing simulation, monitoring and optimization across its lifecycle. Originally developed for applications in aerospace and manufacturing, digital twin technology has recently been extended to healthcare where it enables the creation of virtual models of patient's organs, medical devices and healthcare systems. These models integrate data from multiple sources such as electronic health records, medical imaging, wearable sensors, genomics and physiological measurements. By synchronizing real-world data with computational models, digital twins allow clinicians and researchers to analyse disease progression, predict outcomes and evaluate therapeutic interventions in a risk-free virtual environment. The applications of digital twin technology in healthcare are diverse and rapidly expanding. At the patient level, digital twins support personalized medicine by enabling individualized treatment planning, drug response prediction and disease risk assessment. At the organ and cellular levels, digital twins are used to model complex biological processes, aiding in understanding disease mechanisms and optimizing surgical procedures. Furthermore, digital twins play an important role in medical device development, clinical trials and hospital operations by improving system efficiency, reducing costs and enhancing patient safety. As healthcare systems increasingly emphasize value-based care and data-driven decision-making, digital twin technology offers a promising framework for integrating artificial intelligence, big data analytic and real-time monitoring. Despite challenges related to data interoperability, model validation and ethical considerations, the growing adoption of digital twins highlights their transformation potential in shaping the future of healthcare. This review aims to explore the key applications of digital twin technology in healthcare, discuss current advancements and highlight future directions and challenges.

2. APPLICATIONS OF DIGITAL TWIN TECHNOLOGY

Digital twin ttechnology enables the creation of virtual replicas of physical systems that are continuously updated using real-time data. By integrating sensors, computational models and analytic, digital twins support monitoring, simulation and predictive analysis. Originally developed for industrial applications the technology has expanded into multiple domains due to advances in IoT, artificial intelligence and cloud computing. In healthcare digital twins are increasingly used to model patients, medical devices and hospital systems. These applications support personalized treatment planning, disease progression analysis and clinical decision-making. Digital twins also enhance operational efficiency by enabling predictive maintenance and resource optimization. Virtual experimentation through digital twins reduces risks and costs associated with real-world testing. Furthermore, the technology supports early detection of anomalies and performance degradation. Despite its potential, challenges such as data integration, privacy and model accuracy remain. Overall, digital twin technology represents a promising approach for improving system intelligence and healthcare outcomes. Following are applications of digital twin technology in health care.

2.1. PERSONALIZED MEDICINE DEVELOPMENT

Personalized medicine tailor's treatments and medical procedures to the unique needs of each patient [1]. This approach's basic premise is that treatments should be customized based on variables such as genetic composition, environmental influences, lifestyle choices and comprehensive clinical data rather than relying on a standard model. PM strives to provide care that closely matches the distinct biological and contextual characteristics of every patient. This framework states that precision medicine uses personal data, including genetic traits, environmental exposures and behavioral patterns, to improve disease identification, diagnosis and treatment [2]. Although the strategy presents encouraging developments, it also faces persistent difficulties, especially those pertaining to guaranteeing fair access to emerging technologies and safeguarding patient information. PM aims to improve early detection, prevention and therapeutic decision-making by examining a person's genes, proteins and surroundings [3]. Personalized genomics is crucial for developing patient specific profiles that integrate genetic and genomic information with clinical and environmental factors. Enhancing preventive, diagnostic and treatment strategies while encouraging a more personalized healthcare experience is the aim of this combined analysis [4].

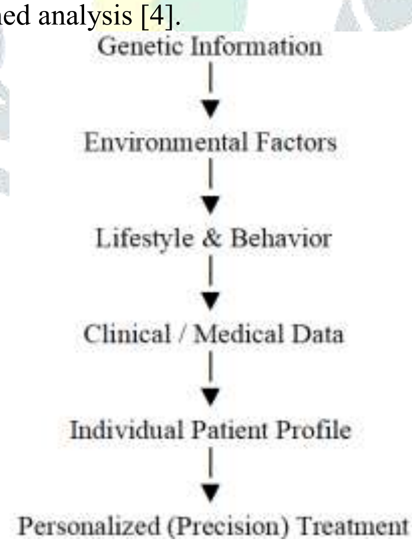

Figure No. 1: Personalized medicine development

2.2. MEDICAL EQUIPMENT

In order to implement sensor-based applications in the healthcare sector, data must be gathered from sensing terminals and linked to particular equipment assets. One of three terminal types is commonly used in industrial internet identification systems. Dynamic energy identifiers monitor medical equipment's operational state in real time. One of these identifiers is present on every device currently in use. The terminal continuously collects and uploads data about the device's operating conditions once it is turned on. Environmental identifiers that are dynamic are medical space condition monitoring terminals. Every clinical area has these low-power, wide-area communication devices installed to record and transmit environmental quality indicators in real time. The binding and distribution of spatial master data are finished by proactive positioning and labeling terminals. They facilitate room-level equipment positioning and link device data to the hospital's equipment ledger and current asset deployment in conjunction with the medical device status monitoring terminals. This facilitates the development of intelligent, dynamic QR code-based identifiers. Using these identifiers as links, the system creates a cloud-based asset database with original asset card records, location photos, equipment identification photos and other relevant visuals.

Asset Terminal Type	Functional Capability	Strategic Role
 **Dynamic Energy Identifiers**	Real-time operational state monitoring.	Continuous tracking of equipment *Performance, energy usage, and asset health*
 **Environmental Identifiers**	Monitoring of clinical space conditions (Temperature, humidity, air	LPWA-based quality control, *Patient safety, and regulatory compliance*
 **Proactive Positioning Terminals**	Room-level spatial identification and tracking.	Accurate asset location, efficient asset utilization and loss prevention

Table No.1: Digital twin technology in medical equipment's

2.3. MEDICAL OPERATION SUPPORT RESOURCE COORDINATION MANAGEMENT PLATFORM

By creating a virtual representation of a physical system, digital twinning enables the modeling, monitoring and optimization of real-world processes through digital simulations. In order to enable complete digitization of these entities, this approach in medical institutions depends on developing a comprehensive master data model that captures the physical environment's structure, including organizations, hospital campuses, buildings, floors, rooms and specialized spaces. Digital twins are a cutting-edge technology that improves the intelligence, speed and accuracy of healthcare services. Digital twins create a dynamic connection between real-world assets and their digital models by utilizing virtual–physical interaction, integrated data analytics and iterative decision-support mechanisms. Intelligent management features like inventory tracking, equipment localization, environmental alerts, fault detection and maintenance optimization are made possible by this connection. Through digital twinning, these capabilities allow for more proactive, effective and data-driven operations in healthcare settings [5], [6].

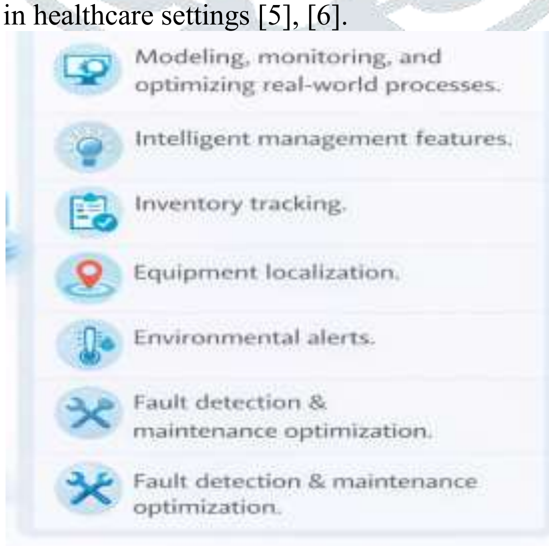

Figure No.2: Medical operation support resource coordination management platform

2.4. SURGICAL SECTOR TECHNICAL FRAME WORK

A wide range of physical injuries, diseases and anatomical abnormalities of the human body are diagnosed, treated and managed by skilled surgeons in the specialized field of surgery. Surgical care frequently necessitates precise incisions to access internal structures and may involve repositioning body parts, remove diseased organs or repair damaged tissues. Since the sixteenth century, surgery has come a long way. Surgery has developed into a very complicated and vital part of contemporary healthcare because of ongoing advancements in medical science and technology. The current state of surgical practice and its continuous development are discussed in this section [7], [8].

2.4.1. Diagnosis Process

The process of diagnosing a disease or other medical condition in the human body is known as diagnosis. It starts with evaluating the patient's symptoms and frequently entails performing a number of clinical tests for a precise assessment. When a patient seeks medical care, the physician suggests certain tests based on the symptoms noted. Blood tests, imaging tests like MRIs, CT scans or X-rays as well as other diagnostic instruments like ECGs may fall under this category. After reviewing the test results, the physician creates a treatment plan based on the patient's medical history and general health.

2.4.2. Traditional Equipment

A thorough assessment of the patient's condition is necessary for the diagnostic procedure. Medical professionals use a variety of devices that are customized to the patient's symptoms in order to support this assessment. These diagnostic tools assist medical professionals in precisely diagnosing the condition and selecting the most effective course of treatment.

2.4.3. Existing Health Management

The health management sector includes doctor coordination, nursing services and patient care but the current system is ineffective. As a result, many patients struggle to get timely treatment, which can have negative consequences. Post-surgery care is also difficult to manage because patients often require continuous monitoring that traditional systems are unable to adequately provide. These limitations cause a number of challenges for people.

2.4.4. Patient's Supervision

Providing appropriate medical care remains a challenge in traditional healthcare systems. Major obstacle. Many patients do not receive the care they require because access to cutting-edge treatments is frequently restricted, especially in rural areas. Additionally patient outcomes may be impacted by the unreliability of certain medical devices used in treatment. Electric shocks are used by defibrillators to restore the heart's regular rhythm. However, if the treatment is not given right away, its efficacy may be limited. Pacemakers, preserving a constant heartbeat and pacemakers control the heart's rhythm. Serious problems including death could result from the device moving or malfunctioning.

2.4.5. Doctor and Staff Administration

The lack of physicians compared to the number of patients is one of the primary problems with traditional healthcare systems. Because each doctor must manage a large number of patients, it is difficult to provide individualized care which leads to long wait times and treatment delays. The efficacy and efficiency of the conventional system are compromised by this restriction. Using robots or automated systems to help with medical tasks could be a workable solution to this problem. Similarly, the use of robotic assistance in these roles may help alleviate the scarcity of nurses and other healthcare professionals.

2.4.6. Features of the Current Sector

Many problems prevent the current healthcare system from providing the best care. Some of the main issues include low doctor-to-patient ratios, high surgical costs, outdated diagnostic tools, hazardous clinical settings, a shortage of physicians and specialists, telehealth inefficiencies, poor interoperability, data security risks, inadequate rural healthcare and reliance on traditional treatment methods. To solve these problems, a more advanced system incorporating modern automation and robotics is needed. In addition to enabling remote healthcare services and improving productivity, accessibility and overall care quality, a system that integrates robotics and the Internet of Things could intelligently detect and correct errors [9].

Category	Description/ Issues	Examples/ Impacts
Diagnosis Process	Disease identification using clinical tests	Blood tests, MRI, CI, X-ray, ECG
Traditional Equipment	Use of conventional diagnostic tools	Defibrillators, pacemakers
Patient Supervision	Limited access to timely medical care	Delayed treatment, device risks
Doctor & Staff Administration	Shortage of healthcare professionals	Long wait times
Existing Health Management	Efficient coordination and monitoring	Poor post-surgical care
Current Sector Challenges	Technological and structural limitations	High cost, rural gaps

Table No.2: Surgical healthcare challenges

2.5. MEDICAL EDUCATION

A lack of internship opportunities, inadequate interdisciplinary integration, a lack of support for individualized learning and assessment, a reliance on constrained teaching methods a gap between theoretical knowledge and clinical application and an unequal distribution of educational resources are just a few of the numerous problems with traditional medical education. When combined these issues lower the overall effectiveness and Caliber of medical education. Digital twin technology offers a potential remedy for these limitations. Through high-precision data collection, modelling and analysis, DT enables the creation of incredibly realistic virtual and physical learning environments. Students can engage with medical concepts and procedures more practically and intuitively in these settings. By developing interactive simulations that lead students through every stage of the learning process and react to their actions in real time, digital twin technology is revolutionizing medical education. Research indicates that students who participate in DT-based simulations outperform those who receive traditional training in clinical practice. Because DTs are repeatable, students can practice skills repeatedly, supporting the trial-and-error method that is essential to medical education. Additionally, DTs enable personalized learning by tailoring the content and level of difficulty to each student's skill level and developmental stage. Additionally, DTs support a more equitable distribution of educational resources by removing time and location barriers [10].

Challenges in Traditional Medical Education	Digital Twin Technology Solutions
• Limited internship opportunities • Lack of interdisciplinary integration • Insufficient support for individualized learning • Rigid teaching methods • Gap between theory and practice • Unequal distribution of resources	• High-Precision Virtual-Physical Simulations • Realistic, interactive virtual environments • Bridging the gap between theory and clinical practice
• Lack of Hands-On Experience	• Interactive, Real-Time Training • Step-by-step clinical simulations • Immediate feedback and practice
• One-Size-Fits-All Approach	• Personalized Learning Paths • Adaptive content and difficulty levels • Customized to individual skills
• Resource Inequity	• Accessible & Equitable Learning • Remote, scalable education • Equal access for all students

Table No.3: Medical education with digital twin technology

2.6. RADIOLOGY

A real-time virtual replica of a physical system or object is called a digital twin. By simulating patients or medical equipment, these models can be used in radiology to assess performance, test modifications and foresee potential problems without affecting the real counterpart. By continuously integrating real-time data, digital twins support individualized treatment, improve early diagnosis and enable virtual clinical trials. This approach goes beyond traditional simulations by offering predictive insights and practical guidance for optimizing healthcare processes, despite ongoing implementation challenges [11]. By enabling real-time, remote monitoring of vital equipment like CT and MRI machines, digital twins have the potential to fundamentally alter healthcare, particularly in radiology [12]. These digital models predict a device's future performance and provide insights into its past. They can identify possible problems early on, recommend fixes and stop issues before they start because of AI. Longer equipment lifespans, reduced downtime and proactive maintenance are all made possible by this continuous data flow, all of which are essential for maintaining dependable, high-quality care. A radiological device's sensors generate a digital twin by sending data for remote analysis. It takes specific human knowledge of the device's operation to comprehend this data. Effective remote support for the radiological device is made possible by combining human expertise with machine-generated data and using AI to find patterns.

For new technologies to be maintained and developed more quickly, digital twins are crucial. They are used, for instance, by NASA and Formula One to design and improve automobiles, enabling rapid testing and simulations that would otherwise take years. These digital models do away with the need for pricey physical models and enable thorough system analysis and optimization. Digital twin is a dynamic, data-driven model that helps businesses predict future trends and learn about past and present operations by replicating the structure, context and behavior of a physical system. In radiology departments, this technology can speed up procedures, lower operating costs, enhance patient experiences and improve overall care quality. The digital twin enables simulations that look at various scenarios by using a four-dimensional model, which helps to maximize both cost-efficiency and service quality [13].

Aspect	Key Point's
Digital Twin	Real-time virtual model of patients or medical equipment
Data Integration	Uses continuous sensor data from CT, MRI, and other devices
Role of Al	Predicts failures, detects patterns, and supports decision-making
Remote Monitoring	Enables real-time performance tracking and maintenance
Clinical Benefits	Early diagnosis, personalized treatment, virtual trials
Operational Impact	Reduces downtime, costs, and improves care quality

Table No.4: Digital twin in Radiology

2.7. REHABILITATION AND PHYSICAL THERAPY

In the fields of physiotherapy and rehabilitation, wearable technology, sensors, imaging and medical records are used to create dynamic digital representations of a patient's physical condition called "digital twins." Medical professionals can use these models to predict recovery paths, test treatment options virtually and modify therapy when a patient's condition changes. DTs offer a reliable framework for tracking progress and supporting data-driven decisions because rehabilitation necessitates frequent adjustments and long-term monitoring. By facilitating virtual therapy sessions and remote supervision, they also increase access to care. DTs can increase adherence and make exercises more engaging when combined with immersive technologies like VR or AR [14], [15], [16]. Compared to acute care, these digital therapies will be more technologically compatible with medium- and long-term treatment options. They will probably develop a hybrid model that blends home-based, outpatient and hospital methods. In order to better predict rehabilitation outcomes, this change will place a higher priority on patient independence, adherence to therapeutic guidance and objective monitoring of daily behaviors.

2.8. COACHING FOR PHYSICAL ACTIVITIES

The rapid development of smart technologies, such as smartphones and smartwatches, as well as advancements in AI algorithms, has made a new era of coaching possible. These advancements could make coaching more accessible and customized, helping people to perform better across a range of domains. With the use of AI-driven insights, Smart Coaching is well-positioned to offer tailored guidance and support to a larger audience, helping people reach their objectives and maximize their potential [17]. Digital twin coaching is a new multidisciplinary field that combines machine learning, human-computer interaction and other technologies. Since the field is still in its early stages, research is still being done to identify the key components of effective coaching systems. We separated the research articles in this survey into three primary categories based on the coaching system's focus: sports, rehabilitation and well-being. Additionally, we provided an overview of the commonly used platforms, tools, sensors and algorithms. We also discovered similarities between the reviewed studies. These insights could be very useful for future researchers exploring the potential of digital twin coaching. To improve Direct-to-Consumer Smart Coaching, researchers must focus on a few key areas. Particularly when it comes to Digital Twin Coaching, there is still a lot to learn about security and privacy. To improve Direct-to-Consumer Smart Coaching, researchers must focus on a few key areas. Particularly when it comes to Digital Twin Coaching, there is still a lot to learn about security and privacy. Additionally, there are a lot of fascinating research directions that could improve DT Coaching. These include improving data collection and interaction with sophisticated smart devices, creating standards for better communication between DTs and other technologies and incorporating haptic feedback into the system to enhance user experience. These advancements are just a few of the exciting prospects for innovation in this field.

Area	Key Points
Digital Twin (DT)	Dynamic digital model using sensors, wearables, imaging, and records
Rehabilitation Use	Predicts recovery, tests therapies, adapts treatment
Remote Care	Virtual therapy sessions and remote supervision
Patient Engagement	Improved adherence using VR/AR exercises
Care Model	Hybrid care: home-based, outpatient, hospital
Smart Coaching	Al-driven personalized coaching
DT Coaching Domains	Sports, rehabilitation, well-being
Future Challenges	Security, privacy, standards, advanced sensors

Table No.5: digital twin in Physiotherapy, Rehabilitation and smart coaching

2.9. PERSONALIZED MEDICINE REQUIRE EPIDEMIOLOGICAL DATA

Digital twin (DT) technology has the potential to transform personalized medicine, but its impact is constrained by the lack of a solid foundation in epidemiological data and mathematical modeling. Although computational advances have accelerated the process, clinical adoption still faces significant challenges, including fragmented data infrastructure, limited model validation and challenges integrating DT solutions into routine care [18]. This viewpoint emphasizes that in order to fully represent the complexity of real-world populations, long-term health patterns and clinical variability, digital twins need to go beyond theoretical models. Mathematical techniques like differential equations, Markov models and neural networks must be combined with thoroughly verified epidemiological data in order to produce dependable, equitable and clinically significant results. More than just technological advancements are needed to advance digital twins; interdisciplinary cooperation, open regulatory frameworks and models that are comprehensible and representative of a range of demographics are also necessary. DTs should be seen as both personalized care tools and public health tools that can predict risk, inform policy and improve system-wide decision-making as AI develops and healthcare depends more and more on data-driven insights. To fully realize the potential of digital twins, standardized procedures, trustworthy data governance and comprehensive clinical validation must be prioritized. DTs can transform from a promising concept into a practical tool that enhances healthcare's predictability, equity and responsiveness to the needs of both individual patients and broader populations by addressing these factors.

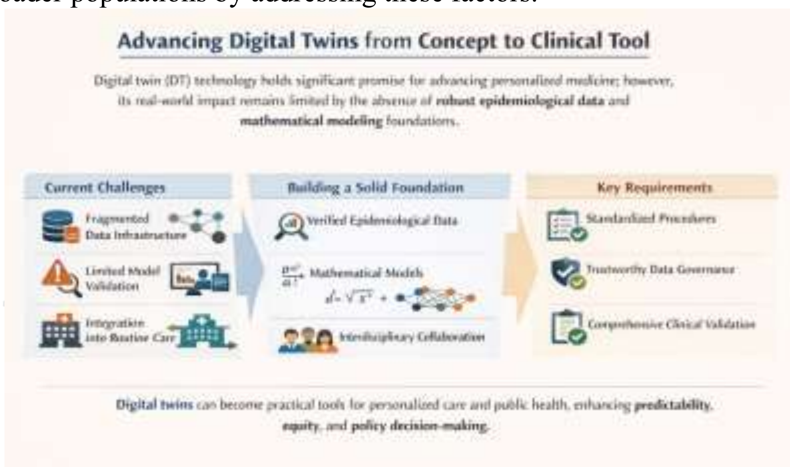

Figure No. 3: Advancing digital twin from concept to clinical tool

2.10. SLMULATING AND OPTIMIZING GERIATRIC HEALTHCARE SERVICES

Digital twin technology is revolutionizing geriatric healthcare by generating dynamic virtual models of patients that can be continuously monitored and analyzed. By using real-time data, AI analytics and predictive simulations, these digital replicas improve hospital workflows, enable more precise medical decisions and offer individualized care. Digital twins have the potential to significantly improve senior citizens' health and quality of life while lowering healthcare costs and preventing complications [19], [20]. Although digital twin technologies present promising solutions, their successful implementation depends on addressing important issues like data privacy, smooth system integration and ethical concerns. Future studies should concentrate on developing regulatory guidelines that guarantee patient data protection and encourage ethical AI use, improving AI-driven predictive models and establishing standardized frameworks to ease the adoption of digital twins in healthcare. The efficiency, predictive capacity and patient-centeredness of geriatric healthcare could all be greatly enhanced by the ongoing development of digital twin technology. By addressing current problems and utilizing cutting-edge technologies, digital twins have the potential to greatly impact the future of elder care, leading to a more intelligent and responsive healthcare system.

Technology Overview	**Creation of real-time virtual models of elderly patients for continuous monitoring and analysis.**
Key Benefits	Improved medical decisions, personalized care, reduced healthcare costs, and complication prevention.
Data & Al Role	Utilizes real-time data, Al analytics, and predictive simulations.
Impact on Elder Care	Enhances health and quality of life for senior citizens.
Implementation Challenges	Data privacy concerns, system integration, ethical issues.
Future Research Directions	Develop regulatory guidelines, enhance Al models, establish standardized frameworks.
Overall Significance	Transforming geriatric care through intelligent and responsive healthcare solutions.

Table No.6: Digital twin in Geriatric healthcare services

2.11. ETHICAL, DATA SECURITY AND REGULATORY CONSIDERATIONS:

Digital twin technology raises important ethical concerns because it relies on continuous collection and analysis of real-time data from physical systems or individuals. One major ethical issue is informed consent, as users must clearly understand how their data are collected, used and stored. Transparency in decision-making is also essential, especially when digital twins are used in sensitive areas such as healthcare, manufacturing safety or urban planning. Another ethical challenge is bias, since inaccurate or incomplete data can lead to misleading digital models and unfair outcomes. Therefore, ethical implementation of digital twins requires accountability, fairness and responsible data use to ensure that technology benefits society without causing harm [21].

Data security is a critical concern in Digital Twin systems because they handle large volumes of sensitive and real-time information. These systems are vulnerable to cyber threats such as unauthorized access, data breaches and manipulation of digital models. Strong security measures including encryption, secure authentication, access control and regular system updates are necessary to protect data integrity and confidentiality. In addition, secure data storage and controlled data sharing mechanisms help prevent misuse of information. Ensuring data security not only protects users but also maintains the reliability and trustworthiness of Digital Twin technology.

Regulatory considerations play a key role in the adoption and implementation of Digital Twin technology. Since digital twins often process personal or operational data, compliance with data protection laws and industry standards is mandatory. Regulations such as data privacy laws, cybersecurity guidelines and sector-specific standards govern how data are collected, processed and shared. In healthcare and industrial applications, regulatory approval may be required to validate the accuracy and safety of digital twin systems. Clear regulatory frameworks help ensure ethical use, protect user rights and promote responsible innovation while reducing legal and operational risks [22].

Ethical Concerns	Digital Twin technology raises ethical issues due to continuous real-time data collection and analysis. Key concerns include informed consent, transparency, bias, and accountability. Ethical implementation requires responsible data use to ensure fairness and prevent harm.
Data Security	Ensuring the security of sensitive, real-time data is critical. Measures such as encryption, secure authentication, access control, regular updates, and sagged controlled data sharing mechanisms are necessary to protect data integrity and confide.
Regulatory Considerations	Compliance with data protection laws, cybersecurity guidelines, and industry standards is mandatory. Regulatory frameworks are needed to ensure ethical use, protect user rights, and validate the safety of Digital Twin systems.

Table No.7: Ethical, Data security and regulatory considerations in digital twin technology

2.12. REMOTE PATIENT MONITORING AND TELEHEALTH:

Remote Patient Monitoring and telehealth are digital healthcare approaches that allow medical services to be delivered beyond traditional clinical settings. Remote Patient Monitoring focuses on the continuous or periodic collection of patient health data such as blood pressure, glucose levels, heart rate or oxygen saturation—using connected devices. This data is transmitted securely to healthcare providers, enabling early detection of health changes and timely clinical intervention. RPM improves chronic disease management, reduces hospital readmissions and enhances patient engagement by allowing individuals to participate actively in their own care from home [23]. Telehealth is a broader concept that includes virtual consultations, follow-up visits, remote diagnosis, health education and digital communication between patients and healthcare professionals. It improves access to healthcare services, especially for patients in rural or underserved areas and minimizes the need for in-person visits. Telehealth also supports continuity of care by enabling regular monitoring and communication, which can lead to better clinical outcomes and cost-effective healthcare delivery. Together, RPM and telehealth represent a shift toward patient-centered, technology-driven healthcare systems [24].

Overview	**Digital approaches that deliver medical services beyond traditional clinical settings through technology.**
Remote Patient Monitoring (RPM)	Focuses on continuous or periodic collection of health data (e.g., blood pressure, glucose, heart rate) using connected devices. Data is securely transmitted to healthcare providers, enabling early detection of health changes and timely intervention. Improves chronic disease management, reduces hospital readmissions and enhances patient participation from home
Telehealth	Includes virtual consultations, follow-ups, remote diagnosis, and digital communication between patients and healthcare professionals. Improves healthcare access, reduces need for in-person visits, and supports continuity of care.
Regulatory Considerations	Includes virtual consultations, follow-ups, remote diagnosis, and digital communication between patients and healthcare professionals. Improves healthcare access, reduces need for in-person visits, and supports continuity of care.

Table No.8: Approaches of digital twin technology in Remote patient monitoring and telehealth

2.13. PREDICTIVE AND PREVENTIVE HEALTH CARE

As one of several tactics to counteract rising health care costs and boost productivity, employers have independently implemented health management programs aimed at improving the health of their employee and spouse populations[25],[26].One According to a 2013 Kaiser Foundation national employer survey, 77% of companies that provide health benefits also fund at least one wellness initiative[27],[28].These initiatives are founded on solid research showing a link between health care costs and modifiable lifestyle choices[29], [30], [31]. The model is based on individualized care, integrating personalized preventive medicine and wellness management, while delivering high levels of coordination within the treatment milieu [32],[33]. The delivery system includes greater focus on evidence-based preventive services, increased physician availability to improve management of patient health and increased access to other health care resources [34]. Second-stage regressions are frequently necessary to correct for skewed medical expenditure distributions, which are frequently prevalent in the healthcare industry and to eliminate any residual case mix differences following matching. Exponential Conditional Mean (ECM) regression models were employed in a final set of medical expenditure statistical analyses to determine how the program affected trends in medical expenditure in comparison to non-members [35]. Healthcare has been at the forefront of applications of artificial intelligence (AI) since its early inception. Expert systems are among the earliest types of AI. Knowledge-based systems also known as expert systems or KBS, are intelligent systems that capture the expertise of a skilled individual. KBS are a unique type of intelligent system that heavily relies on knowledge. KBS were initially implemented in the 1960s while gathering medical expertise from medical professionals. Because KBS make decisions using heuristic rather than algorithmic methods, they differ from traditional software systems and data analytical systems [36].

Aspect	Description
Health Management Programs	Employers independently implement health management programs to enhance employee and spouse health and limit rising healthcare costs. A 2013 Kaiser Foundation survey showed 77% of companies with health benefits fund at least one wellness initiative. These initiatives link healthcare costs to lifestyle choices, focus on individualized care, preventive services, and physician availability.
	Second-stage regressions are used to correct skewed healthcare expenditure data, addressing case mix differences. Exponential Conditional Mean (ECM) regression models assess the impact of health programs on medical expenditure trends.
Statistical Analyses	Healthcare has applied Al since the 1960s, starting with expert systems, which are knowledge-based systems (KBS) capturing medical expertise. KBS use heuristic methods for decision-making, unlike traditional algorithmic systems, capturing and applying human expertise.
Artificial Intelligence in Healthcare	Healthcare has applied Al since the 1960s, starting with expert systems, which are knowledge-based systems (KBS) capturing medical expertise, KBS use heuristic methods for decision-making, unlike traditional algorithmic systems, capturing and applying human expertise.

Table No.9: Predictive and preventive health care

CONCLUSION

In conclusion, Digital Twin technology holds considerable promise to transform modern healthcare systems by bridging the gap between physical and digital domains. Continued research, technological innovation and regulatory support will be critical to fully harness its potential and establish Digital Twins as a foundational component of future healthcare delivery and personalized medicine. Digital Twin technology represents a paradigm shift in healthcare by enabling the creation of virtual replicas of patients, clinical processes and healthcare systems that evolve in real time through continuous data integration. Its applications across disease modeling, diagnosis, treatment planning, medical device design, hospital operations and personalized medicine demonstrate significant potential to enhance clinical decision-making, patient safety and overall healthcare efficiency. By allowing simulation of disease progression and therapeutic interventions, Digital Twins support predictive, preventive and precision healthcare approaches. However, the widespread adoption of Digital Twin technology in healthcare is challenged by issues related to data quality, interoperability, cybersecurity, ethical considerations and regulatory validation. Addressing these challenges through standardized data frameworks, robust governance models and interdisciplinary collaboration among clinicians, engineers and policymakers is essential.

REFERENCES

[1]. Björnsson, B. Borrebaeck, C. Elander, N. Gas slander, T. Gawel, DR and Gustafsson, M. 2020, Digital twins to personalize medicine. (2020) 12(1):4.

[2]. Stefanicka-Wojtas, D. Karpas, D. 2023.Personalized medicine—implementation to the healthcare system in Europe. (2023) 13(3):380.

[3]. Available online at: https://www.hcltech.com/trends-and-insights/digital-twintrends-2024 (Accessed December 31, 2019).

[4]. Terrie, YC. 2023."Advancing research in personalized medicine". US Pharm. (2023) 13:31–6.

[5]. Shamilah, A. Awad, M. and Farhat, 2019. "IoT based predictive Maintenance management of medical equipment". Med Syst 2019; 44(4).

[6]. Liu, WR. Li. B. and Ji. ZY. 2020."Application of telemedicine Technology in the prevention and treatment of Respiratory infectious diseases". China Med Equip 2020,35(06):108,111,120.

[7]. Drageset, S. Lindstrøm, T.C.and Underlid, 2010. "Coping with breast cancer: Between diagnosis and surgery". vol. 66, no. 1, pp. 149–158, Jan. 2010.

[8]. Batth, RS. Nayyar, and Nagpal, 2018. "Internet of Robotic Things: Driving intelligent robotics of future-Concept, architecture, applications and technologies". Aug. 2018, pp. 151–160.
[9]. Batth, RS. Nayyar, and Nagpal, 2018. "Internet of Robotic Things: Driving intelligent robotics of future—Concept, architecture, applications and technologies". 4th Int. Conf. Compu. Sci. (ICCS), Aug.2018.151,160.
[10]. Chen, SS. Wang, HZ. Xia, T. Xu, LY. and Leng, J. 2022, "Construction and application of intelligent medical Imaging laboratory based on digital twin technology". 39(10),101-107.
[11]. Simonds, S. "Millions of Things Will Soon Have Digital Twins".
[12]. Bruyn Seels, K. Santoni de Sio, F.van den Hoven, J.2018, "Digital Twins in Health Care: Ethical Implications of an Emerging Engineering Paradigm". 2018, 9, 31.
[13]. Glasse gen, E.H. Stargel, D.S; 2012. "The digital twin paradigm for future NASA and US Air Force vehicles
[14]. Rojek, I. 2010. "Neural networks as performance improvement models in intelligent CAPP systems". 39, 55–68.
[15]. Sondej, T. Zawadzka, 2022, "Influence of cuff pressures of automatic sphygmomanometers on pulse oximetry measurements". 2022, 187, 110329.
[16]. Piotrowski, Z.2013 Drift Correction Modulation scheme for digital signal processing. *Math. Computer Model.* 2013, *57*: 2660–2670.
[17]. Davis, L. Appleby, R. Davis, P. Wetherell, M. Gustafsson, 2018. "The role of coach-athlete relationship quality in team sport athletes' psychophysiological exhaustion: Implications for physical and cognitive performance". J. Sports Sci. 2018, 36, 1985–1992.
[18]. Vallée, 2024. "Envisioning the future of personalized medicine: role and realities of digital twins". May 13, 2024;26: e50204.
[19]. Shamay Leh, A. Awad, M. Farhat, J.2019, "IoT based predictive maintenance management of medical equipment". J Med Syst 2019; 44(4).
[20]. Shamay Leh, A. Awad, M. Farhat, J.2019 "IoT based predictive maintenance management of medical equipment". J Med Syst 2019; 44(4).
[21]. Florida, L. 2019, "Cowls Ethical governance of data-driven technologies Philosophy & Technology". 32 2019.
[22]. Rumbold, J.M.M. Pierscionek, B; 2017. "The effect of the General Data Protection Regulation on medical research Journal of Medical Internet Research".19(2) 2017.
[23]. Kvedar, J. Coye, M.J. Everett, W.2014."Connected health: A review of technologies and strategies to improve patient care Health Affairs" .33(2) 2014.
[24]. Bashshur, R. Shannon, G. Smith, B. Alverson, and Antoniotti, 2014. "The empirical foundations of telemedicine interventions Tele medicine and e-Health". 20(9)2014.
[25]. ADP Research Institute. http://www.adp.com/tools-and-resources/adp-research-institute/research and-trends/~/media/RI/whitepapers/. Accessed February 5, 2014.
[26]. The Kaiser Family Foundation and Health Research & Educational Trust. 2013,2014 Employer Health Benefits.Accessed February 5,2014.
[27]. Goetzel, RZ. Anderson, DR. Whitmer, RW. "The relationship between modifiable health risks and health care expenditures". 1998; 40:843–854.
[28]. Kowlesar, NM. Goetzel, RZ. Carls, GS. Tabrizi, MJ. Guindon, A. "The relationship between 11 health risks and medical and productivity costs for a large employer". 2011; 53:468–477.
[29]. Yen, L. Schultz, A. Schnueringer, E. Edington, D. "Financial costs due to excess health risks among active employees of a utility company". 2006; 48:896–905.
[30]. Goetzel, RZ. Pei, X. Tabrizi, MJ.2012, "Ten modifiable health risk factors are linked to more than one-fifth of employer-employee health care spending".2012;31:2472 2484.
[31]. White, J. Hartley, SK. Musich, S. Hawkins, and Ozminkowski, RJ.2013. "A more generalizable method to evaluate the association between commonly reported health risks and healthcare expenditures among employers of all sizes". J Occup Environ Med. 2013; 55:1179–1185.
[32]. Klemes, A. Seligmann, RE. Allen, L. Kubica, MA. Warth, and Kaminetsky, B; 2012, "Personalized preventive care leads to significant reductions in hospital utilization". Am J Manag Care. 2012;18: e453–e460.
[33]. Seligmann, RE. Gassner, LP. Stolzberg, ND. Samarasekera, NK. Warth, and Klemes, A. 2012. "A personalized preventive care model versus a traditional practice: comparison of HEDIS measures". 2012;18: e453–e460.
[34]. Musich, S. Klemes, A. Kubica, MA. Wang, S. and Hawkins, K.2014."Personalized preventive care reduces healthcare expenditures among Medicare Advantage beneficiaries". 2012;18: e453–e460.
[35]. Diehr, P. Yanez, D. Ash, A; Hornbooks, M. and Lin, DY.1999. "Methods for analyzing health care utilization and costs". Annu Rev Public Health. 1999, (20):125–144.
[36]. Batarseh, F. 2011,2006,2020, "Incremental Lifecycle Validation of Knowledge-Based Systems through Common KADS". 1999, (20):125–144.