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(Research Article)

Digital twin–driven virtual human health monitoring and alert system

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Abstract

The Digital Twin–Driven Virtual Human Health Monitoring and Alert System is designed to assist users in tracking and improving their health through an intelligent digital platform. The system collects essential health parameters such as oxygen saturation, blood pressure, sleep duration, water consumption, and daily physical activity using an interactive chatbot interface. Based on this information, the system creates a dynamic virtual representation of the user's health condition, commonly referred to as a Digital Twin. This virtual model is continuously updated as new health data is provided by the user. Machine learning algorithms analyze the collected data to generate meaningful health insights, including reports, lifestyle suggestions, and preventive recommendations. If any health metric crosses a predefined safety threshold, the system generates alerts to notify the user about potential risks.

Keywords: Digital Twin; Artificial Intelligence; Health Monitoring; Preventive Healthcare; Machine Learning

1. Introduction

The rapid development of Artificial Intelligence (AI) and Data Analytics has significantly influenced many sectors such as healthcare, education, and digital publishing. Among these industries, healthcare has experienced remarkable improvements through the integration of intelligent technologies that support personalized services and continuous monitoring of health information. As more individuals depend on online platforms for health-related information and wellness support, it has become increasingly difficult to identify reliable and relevant medical insights from large volumes of digital content. Users are frequently exposed to an overwhelming amount of health information, which can lead to confusion and difficulty in making informed decisions. This overload of data often reduces user engagement with personal health monitoring and may prevent individuals from identifying useful wellness recommendations.

2. Literature Review

2.1. Michael Grieves, "Digital Twin: Manufacturing Excellence through Virtual Factory Replication", 2014.

Michael Grieves is widely recognized as the pioneer of the Digital Twin concept, which was first introduced in the field of product lifecycle management. His work laid the foundation for creating virtual replicas of physical systems that can monitor and simulate real-world conditions in real time.

2.1.1. Methodology

In his research, Grieves proposed a framework consisting of three main components: the physical entity, the virtual representation, and the data connection between them. The methodology focuses on continuous data exchange between

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the real system and its digital model. This allows the digital twin to update dynamically and simulate system behavior under different conditions, enabling improved monitoring and predictive analysis.

2.2. Koen Bruynseels et al., "Digital Twins in Health Care: Ethical Implications", 2018

Koen Bruynseels and his research team studied the application of Digital Twin technology in healthcare, particularly focusing on how AI and big data can be used to create personalized health models for patients.

2.2.1. Methodology

The researchers analyzed how Artificial Intelligence, big data analytics, and computational modeling can be combined to create a virtual representation of a patient's health condition. Their approach involves collecting patient health data, processing it using advanced analytics, and creating a digital model capable of simulating different medical scenarios to improve preventive healthcare strategies.

2.3. Yong Liu et al., Research on Digital Twin based Healthcare Monitoring Systems

Yong Liu and his research team proposed a cloud-based healthcare framework that integrates Digital Twin technology to support continuous health monitoring and remote healthcare services.

2.3.1. Methodology

The methodology involves collecting user health data through monitoring systems and uploading it to a cloud computing platform. The digital twin model processes the data using cloud-based analytics to generate real-time health insights and risk assessments. This framework enables continuous monitoring and improves the ability to detect gradual health changes over time.

2.4. Haya Elayan et al., IoT-based Healthcare Monitoring Research

Haya Elayan and her colleagues conducted research on integrating Internet of Things (IoT) technology with Digital Twin systems to develop intelligent healthcare monitoring environments.

2.4.1. Methodology

Their research methodology focuses on collecting health data through IoT sensors and wearable devices. Machine learning algorithms analyze the sensor data to detect abnormal health patterns. The Digital Twin model then interprets this information in real time to generate alerts and provide context-aware health insights for users.

2.5. Zhi Chen et al., Machine Learning Applications in Healthcare Systems

Zhi Chen and his research team focused on applying machine learning algorithms to health prediction systems in order to improve early detection of medical conditions.

2.5.1. Methodology

The researchers evaluated multiple machine learning models, including supervised and unsupervised learning algorithms, to analyze large health datasets. These models identify relationships between different health parameters such as blood pressure, sleep patterns, and physical activity. The system then predicts potential health risks and provides early alerts to prevent serious medical conditions.

Table 1 Overview of Existing Work on Digital Twin for Healthcare

S.No	Key Findings	Author(s)	Year	Methodology
1	Demonstrated that Digital Twin technology improves monitoring, predictive analysis, and decision-making processes.	Michael Grieves	2014	Proposed the Digital Twin framework consisting of a physical system, virtual model, and real-time data connection between them. The virtual model is updated continuously using real-world data.

2	Showed that digital twin models can simulate patient conditions and support personalized healthcare solutions.	Koen Bruynseels et al.	2018	Used Artificial Intelligence, big data analytics, and computational modeling to create digital representations of patient health conditions for healthcare analysis.
3	The framework enables continuous health monitoring and provides real-time analysis of patient health conditions.	Yong Liu et al.	2019	Developed a cloud-based healthcare monitoring system where patient health data is collected, stored, and analyzed using digital twin models and cloud computing technologies.
4	The system improves real-time health monitoring and helps detect abnormal health patterns at an early stage.	Haya Elayan et al.	2020	Integrated Internet of Things (IoT) sensors and wearable devices to collect health data that is processed using machine learning algorithms within a digital twin environment.
5	The study proved that machine learning can predict potential health risks and generate early health alerts.	Zhi Chen et al.	2021	Applied machine learning models to analyze health datasets and identify relationships between physiological parameters such as blood pressure, activity levels, and sleep patterns.

3. System Architecture

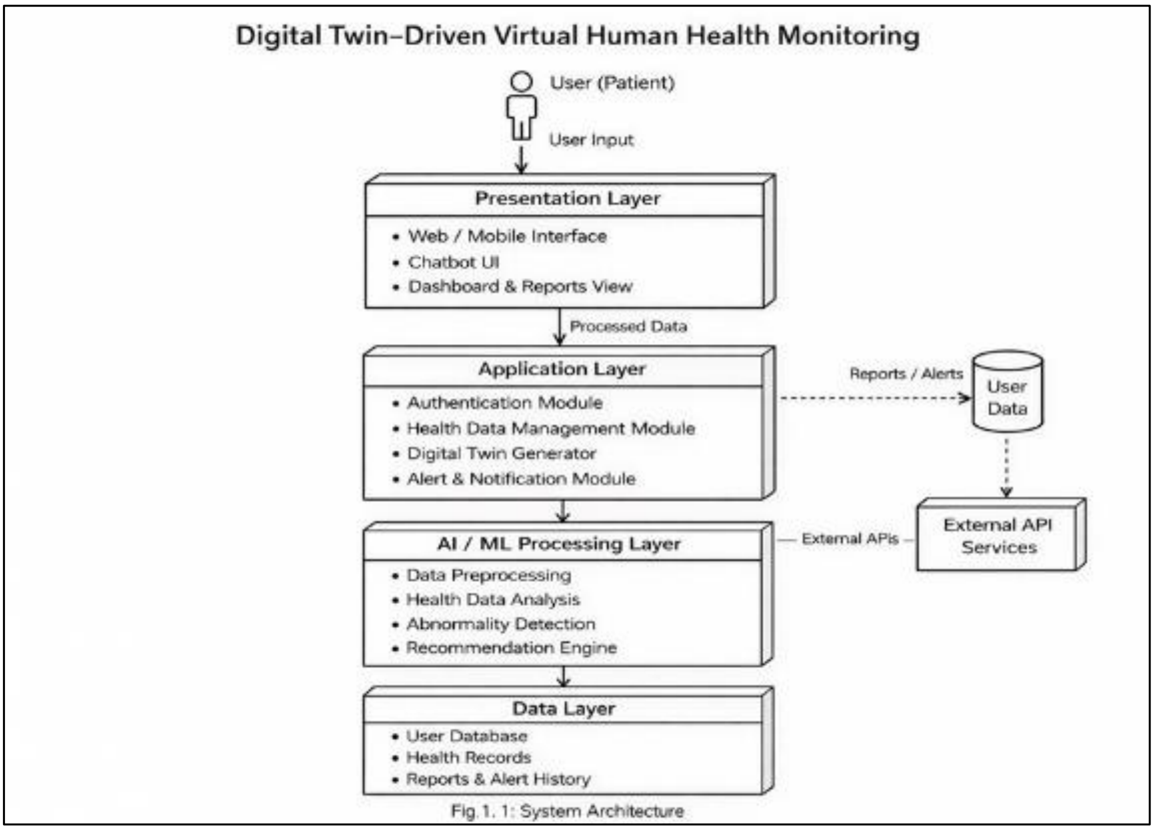

Figure 1 System architecture of the proposed Digital Twin–Driven Health Monitoring System

The Digital Twin–Driven Virtual Human Health Monitoring System is structured using a multi-layer architecture that connects real-world health data with digital analytical processes. This architecture enables continuous monitoring and analysis of user health metrics. The first layer is the Data Collection Layer, where users provide health information through an AI-powered chatbot interface. Parameters such as oxygen saturation, blood pressure, sleep duration, water intake, and physical activity are collected at this stage. The second layer is the Data Storage and Processing Layer, where the collected information is organized and securely stored in a database. This stored information forms the basis of the user's digital twin, which acts as a continuously updated representation of their health condition.

Next, the Analytical Layer applies machine learning algorithms and natural language processing techniques to evaluate the collected data. The system compares real-time user metrics with predefined health thresholds in order to identify unusual patterns or potential health risks. Finally, the Output Layer delivers results to the user. The system generates health reports, provides personalized lifestyle recommendations, and sends alerts if any parameter exceeds safe limits. Through this architecture, the system supports proactive health monitoring and helps users identify potential health issues at an early stage.

4. Proposed Methodology

The proposed **Virtual Human Health Monitoring (VHHM) System** is designed to monitor and analyze patient health information using a digital twin–based approach. The methodology focuses on collecting physiological data, processing the information, and generating a virtual representation of the patient's health condition. The overall workflow of the system consists of several stages including patient registration, health data acquisition, digital twin generation, data analysis, and visualization through an interactive dashboard.

4.1. Objective of Experiment

The objective of this experiment is to develop a Digital Twin–Driven Virtual Human Health Monitoring System that can continuously monitor and analyze a user's health parameters in a virtual environment. The system aims to create a digital representation of a patient that reflects the real-time physiological condition using collected health data.

4.2. Patient Registration and Profile Creation

The first step in the proposed system is registering the patient within the platform. During this process, basic information such as the patient's name, age, and gender is stored in the system database. Each patient profile is assigned a unique identity within the Patient Integrity Registry, which ensures that health data is organized and easily accessible.

This registry acts as the central repository that stores and manages all patient records.

4.3. Health Data Collection

After registration, the system collects important health parameters from the user. These parameters include physiological indicators such as heart rate, body temperature, blood oxygen level, and hydration status. The data may be obtained through wearable devices, manual input, or simulated data used for system demonstration.

These parameters represent the real-time physiological condition of the patient and are continuously updated in the system.

4.4. Digital Twin Generation

Once the health data is collected, the system creates a digital twin model of the patient. A digital twin is a virtual representation that reflects the patient's health status based on the collected physiological data. The model updates dynamically whenever new health data becomes available.

This virtual representation helps simulate the patient's health condition and allows the system to monitor changes in real time.

4.5. Health Data Analysis

The collected health parameters are processed and evaluated using predefined health thresholds and rule-based logic. Each physiological parameter is analyzed to determine whether it falls within the normal range or indicates a potential health concern.

During this stage, the system also calculates a Virtual Twin Viability Score, which provides an overall indicator of the patient's health condition based on multiple health parameters.

4.6. Health Status Classification

After processing the health data, the system classifies the patient's condition into different health categories. These categories may include stable health status or medical intervention required. This classification helps healthcare professionals quickly identify patients who require attention.

5. Algorithm

5.1. Step 1: Patient Registration and Identity Verification

The system begins by registering a patient in the Patient Integrity Registry, where basic personal details such as name, age, and gender are stored. Each patient is assigned a unique digital profile to maintain secure and organized medical records.

5.2. Step 2: Health Data Acquisition

After registration, the system collects physiological parameters including heart rate, body temperature, oxygen saturation levels, and hydration status. These inputs can be obtained from wearable devices, sensors, or manual health data entries.

5.3. Step 3: Digital Twin Initialization

Once the health data is collected, the system generates a **virtual digital twin model** representing the patient's physiological state. This model acts as a real-time digital replica that updates whenever new health data is received.

5.4. Step 4: Data Processing and Health Analysis

The collected physiological parameters are analyzed using machine learning models and predefined clinical thresholds. The system evaluates whether the recorded values fall within normal health ranges or indicate potential medical risks.

5.5. Step 5: Health Status Classification

Based on the analysis results, the system classifies the patient's condition into different categories such as:

- Stable Condition
- Monitoring Required
- Medical Intervention Required

This classification enables healthcare professionals to quickly identify patients who require immediate attention.

5.6. Step 6: AI Diagnostic Recommendation

The integrated AI module generates personalized health recommendations based on the analyzed data. These suggestions may include lifestyle adjustments, hydration reminders, physical activity recommendations, or further medical consultation.

5.7. Step 7: Clinical Data Logging

All observations and diagnostic results are stored in the Clinical Longitudinal Data Repository. This database maintains timestamped records of patient vitals, medical observations, and system-generated diagnoses.

5.8. Step 8: Visualization and Dashboard Updates

Finally, the processed results are displayed on the doctor and patient dashboards. The system updates real-time health metrics, digital twin viability scores, and clinical observations to provide a comprehensive overview of the patient's health condition.

6. Output

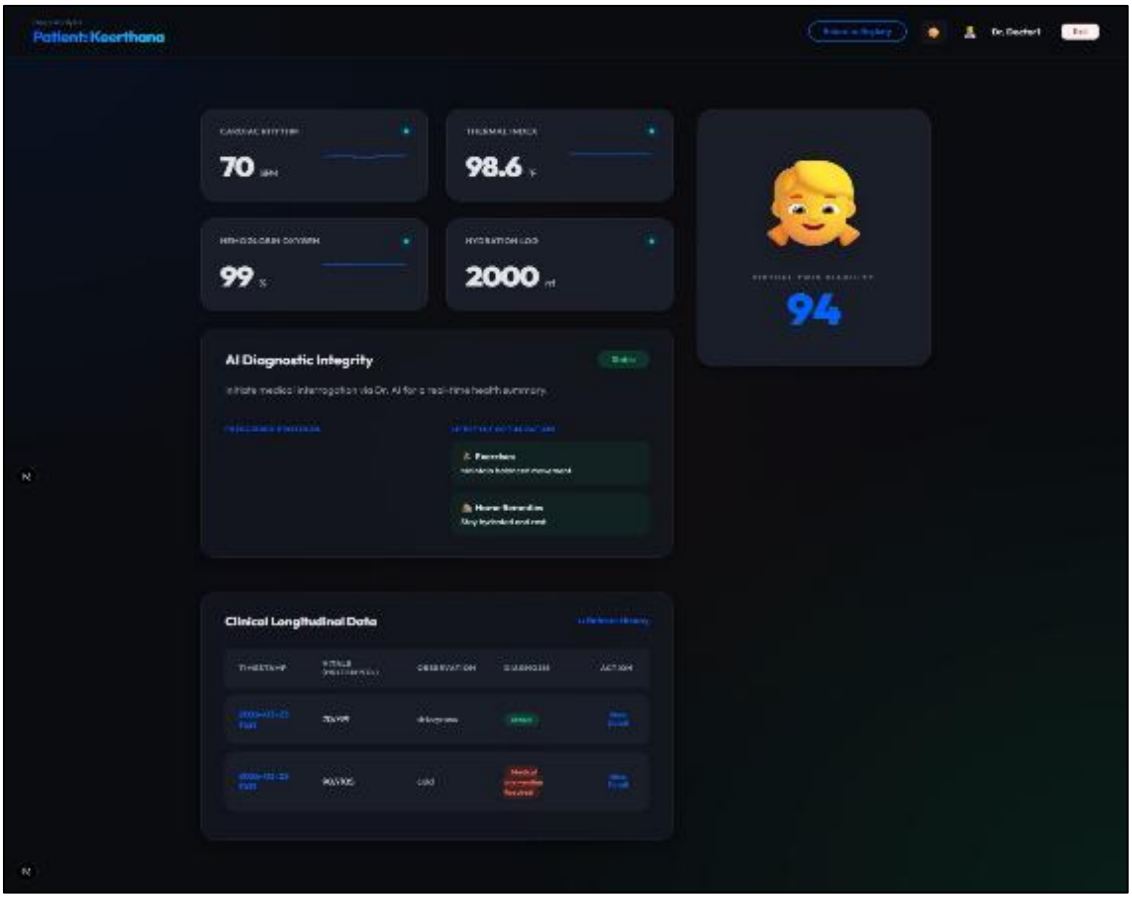

Figure 2 Health analytics and Dashboard

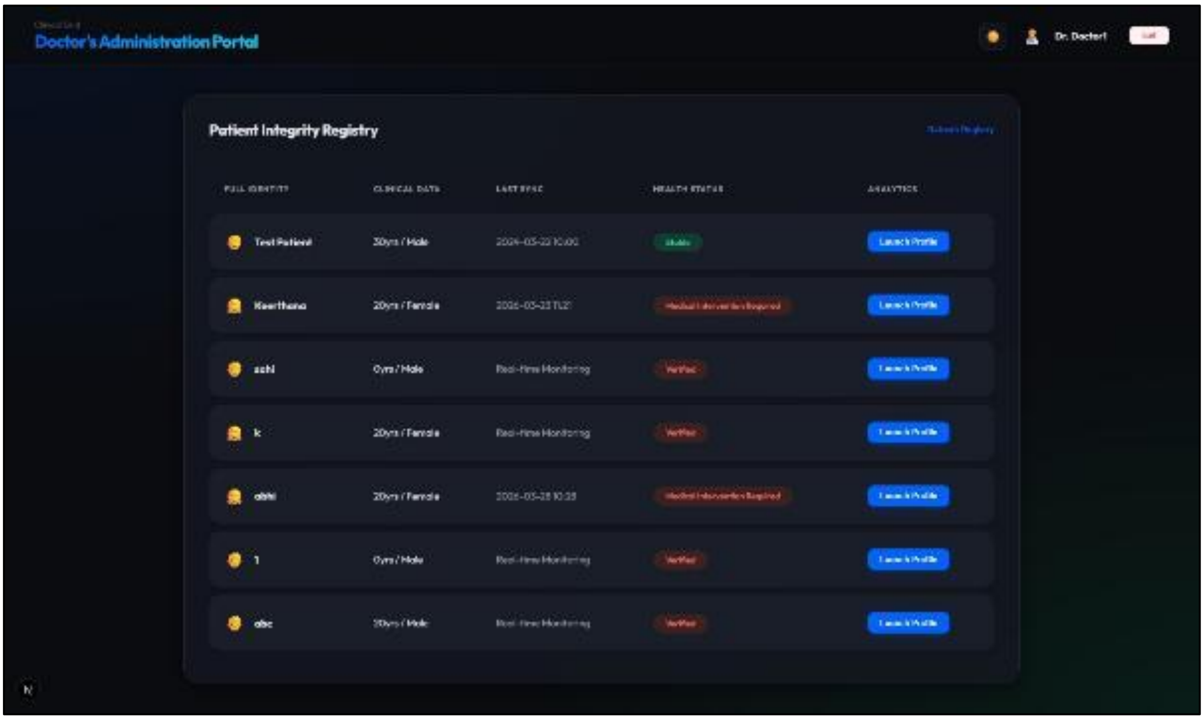

Figure 3 Doctor's administration portal

7. Conclusion

The project demonstrates the potential of combining digital twin technology with artificial intelligence techniques to create intelligent healthcare monitoring systems. Such systems can contribute to improving patient awareness, supporting preventive healthcare, and assisting medical professionals in managing patient data more effectively.

Compliance with ethical standards

Acknowledgment

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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