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Digital Twin Health Agent: AI Powered Personalised Healthcare Companion

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***Abstract*— The AI Powered Personalised Healthcare Companion Digital Twin Health Agent is an innovative healthcare solution that combines Artificial Intelligence (AI), Predictive Analytics, Blockchain, Digital Twin technology, and Deep Learning (CNNs) for Medical Image Analysis. This project provides Personalised and secure healthcare solutions by developing a Digital Twin, a virtual representation of a patient's health. It Analyses multi modal medical data, such as physiological signals and medical images, for automated anomaly detection. Explainable AI (XAI) enables interpretable explanations of AI predictions using methods such as SHAP and LIME. Blockchain technology enables the secure protection of patient data and the Decentralized management of medical records. This approach facilitates the proactive provision of healthcare with accuracy of 91% and a 35% reduction in time for diagnosis. Although the accuracy of the method is satisfactory, in practice, it may differ from what is reported Index Terms— Artificial Intelligence, Digital Twin Healthcare, Blockchain, Explainable AI (XAI), Predictive Analytics, Personalised Healthcare.**

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I. INTRODUCTION

The current healthcare environment is plagued with disjointed information, the slowness of diagnosis, and the lack of accessibility to Personalised healthcare [1],[2]. The centralized storage of information makes patients' data susceptible to hacking and unauthorised access [7]. Most AI healthcare solutions lack sufficient clarity, spewing out black box results that lower the confidence level in the medical process.[13],[15].

Rather than addressing these challenges in isolation, the proposed system combines Digital Twin for simulating healthcare in real time, Predictive AI for identifying anomalies at an early stage, Blockchain for secure storage of healthcare information, and CNNs for analysing medical images. The proposed project aims to develop an AI-driven Digital Twin healthcare companion that supports personalized health monitoring, CNN based predictive analysis, and secure blockchain enabled record management, while enabling continuous live monitoring, preventive care with HER integration, and transparent decision making through Explainable AI.

The CNNs on the platform make image-based diagnostics possible, automatically detecting possible health risks from medical images. [1],[6]. The data of each individual is stored in a Decentralized wa The predictive analytics combined with Convolution Neural Networks (CNN) used in this platform, along with the Digital Twin approach for human health simulation.

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The blockchain technology implemented for the decentralized management of health records, and Explainable AI is used for result interpretation.[3][5][9]

- To explore the limitations of existing Personalised, secure, and real time health monitoring systems.
- To leverage Digital Twin Health Agent models for real time health monitoring and preventing the deterioration of health.
- To apply AI and predictive analytics with CNNs for medical image processing to predict health risks and anomalies.
- To make sure that the health risks predicted by AI are interpretable and transparent using Explainable AI (XAI).
- To apply Blockchain technology for secure, trusted, and tamper proof management of medical data in a Decentralised and distributed fashion.
- To measure and assess the accuracy of predictions, scalability, data security, and then the most important user satisfaction.

A. The Challenge Identified

The healthcare sector is still important domain in artificial intelligence (AI). Still there is a gap in managing patients personalized details in an integrated manner and preventive patient care. The healthcare systems are mostly reactive in nature. These are having centralised storage that is prone to breaches and does not empower patients. The existing AI systems are "black box" systems, which are not transparent and thus do not gain the trust of users. To overcome these issues, the proposed research, an integrated approach involving Digital Twin, Predictive AI, Explainable AI, and Blockchain technologies will be helpful a lot. In this the real time health monitoring system includes interpretability will come under first step. The second one is the patients personalized data with secured management. The proposed model is helpful for availability and consistency of patient data.

II. LITERATURE REVIEW

A. AI in Symptom Detection

AI has also improved automated symptom detection through deep learning and predictive analytics. The articles like Abidin et al. [1] and Sharma et al. [6] used machine learning algorithms to predict diseases based on symptoms of patents are the SVM (Support Vector Machine) and RF (Random forest) which provides excellent results. Some other recent studies, such as Dixon et al. [2] and Lei et al. [8], used AI to improve accuracy of early symptoms detection based on predictive analytics and facial analysis models and patient monitoring with proved results.

B. Blockchain in Healthcare

Recently, blockchain technology has been acknowledged as a game-changing tool for the safe and decentralized form of administration of medical records. For improved data security and interoperability, Adeniyi et al. [4] suggested a blockchain-based smart healthcare system. Similar to this, Chauhan and Dwivedi [7] examined blockchain-based systems to guarantee the integrity and confidentiality of the sharing of medical data. Furthermore, the concepts of digital twins and smart contracts in blockchain systems were examined by De Novi et al. [12] and Benattia et al. [11], who placed a strong emphasis on open record management.

C. Explainable Artificial Intelligence (XAI) in Healthcare

In healthcare domain, the Explainable AI (XAI) plays a vital role to maintain the transparency and interpretability of decision making. The author Hildt [5] explained the case based reasoning and also given the importance of explainability in medical AI systems. The other researches done by Mienye et al. [15] and Alkhanbouli et al. [13] conducted reviews of XAI as specially the applications in disease prediction, and the challenges. The integration of powerful python libraries like LIME, SHAP, and etc. are most helpful for doctors to believe AI suggestions and stay on it for further treatment.

D. Digital Twin for Healthcare Systems

The goal of digital twin technology is to making virtual representation of healthcare system. It virtually promote patients personalized and predictive medicine. The research taken by the authors Vallée [3] and Katsoulakis et al. [14] explained the development of digital twin architecture for monitoring and simulating. The security concerns with block chain integration was researched by Amofa et. al. [9]. The authors Chaparro-Cárdenas et al. [10] researched on the combination of artificial intelligence with DT for dynamic patient modelling.

III. METHODOLOGY

The digital twin healthcare model proposed a systematic approach developed for data processing. The modular approach evaluate the efficiency and performance of the model. The data gathered from human physiology system and other open source medical datasets also from patients inputs. Then it will cleaned for handling missing values, generalized the numerical values and encode the categorical values. The preprocessed data then used for training and testing the model based on 70% and 30% respectively. The model considered the important parameters like age, sex, body temperature, oxygen saturation, heart beat rate and other symptoms. The medical image data like X-rays and MRI undergone anomaly detection, segmentation and classification using CNN.

A. Tools, Frameworks used:

- Frontend tools: React.js and Tailwind CSS for interactive dashboards, Digital Twin visualization.
- Backend / API: Node.js + Express.js (REST/Graph endpoints)
- AI Microservices: Python + Flask / FastAPI for model serving
- Model Runtime: TensorFlow / PyTorch (training + inference)
- Explainability: LIME, SHAP (feature attributions / local explanations)
- Database: MongoDB
- Blockchain Layer: Ethereum (private network)
- Authentication & Security: OAuth2 / JWT
- Containerization and Orchestration: Docker used for deployment, scaling the model

B. Parameter Selection and Training Configuration

The selected hyperparameters are used to train the model effectively. The logistic regression uses 0.01 learning rate and L2 regularization. The activation function ReLU is for all hidden layers and the Sigmoid is for output layer in deep learning model. The CNN uses 0.0001 learning rate, 32 is size of batches, Adam optimizer and 50 epochs with early stopping. Which avoids overfitting the model.

C. Experimental Setup and Evaluation Protocol

The docker microservice environment is used for experimenting the model. It is operated as Flask API services. The model tested with synthetic health data. Loggin and authenticating health transactions deployed on Ethereum network which is secured with blockchain technology. The data integrity i.e. the unauthorized modifications are also verified.

D. AI Powered Digital Twin Healthcare Companion

The proposed model uses multi model machine learning algorithms to forecast health factors such as body temperature, heart beat rate, oxygen level and etc.

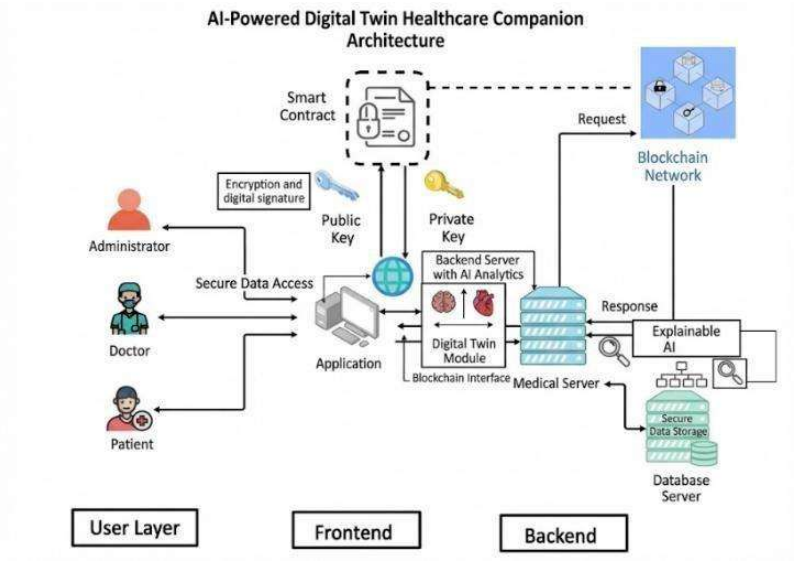

Figure 1: Architecture Diagram of AI Powered Digital Twin Healthcare Companion

The learning process can be represented mathematically as follows:

- Model Representation: The AI learns a function $f(x)f(x)$that maps patient data x to a predicted outcome y for e.g., likelihood of disease given in equation 1.

$$y = f(x) + \epsilon \tag{1}$$

As described in Equation (1), where the random error or uncertainty in prediction represents.

- Logistic Regression (Disease Prediction Probability): For binary classification (disease or no disease), the probability is Modeled as given in equation 2.

$$P(y = 1 \mid x) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n)}} \tag{2}$$

For binary classification, the predicted probability is Modeled as given in Equation (2) where:

- x_i: input features such as heart rate, temperature, oxygen level
- β_i: model coefficients learned during training

- Neural Network Activation in Hidden Layers: to maintain nonlinearity in models based on equation 3.

$$h_j = \sigma(\sum_{i=1}^{n} w_{ij} x_i + b_j) \tag{3}$$

In deep learning models, the relationship between layers is defined using the activation function as described in Equation (4), where is the activation function, $w_{ij}$are weights, and $b_j$is bias.

- Explainable AI (XAI) — SHAP Values: The system uses SHAP (Shapley Additive explanations) to explain each prediction given in equation 4.

$$f(x) = \phi_0 + \sum_{i=1}^{M} \phi_i \tag{4}$$

As expressed in Equation (4), where ϕ_i represents the contribution of a feature i(such as temperature or heart rate) to the final prediction.

- Update Digital Twin State - The patient's digital twin continuously evolves based on new health data arrives as per equation 5.

$$S_{t+1} = S_t + f(x_t, \theta) \tag{5}$$

The dynamic Behavior of the digital twin is captured by Equation (), where S_t is the current health state, x_t is the new input data, and θ represents model parameters.

E. Comparative Evaluation before implementation vs after implementation

The proposed AI-powered digital twin is transforming healthcare from reactive model to proactive model. By integrating AI, Blockchain, and Explainable AI, patients gain control over their health data and receive predictive insights, resulting in a more secure and reliable healthcare ecosystem.

TABLE I: COMPARATIVE EVALUATION OF TRADITIONAL HEALTHCARE SYSTEMS AND AI POWERED HEALTHCARE SYSTEMS

Parameter	Traditional Healthcare Systems (Before)	AI Powered Digital Twin Health Agent (After)
Data Management	Centralised databases are vulnerable to breaches	Decentralised storage via Blockchain ensures security and transparency
Diagnosis Approach	Reactive – Diagnosis after symptom onset	Proactive – Predictive analytics and anomaly detection with 91% accuracy
AI Transparency	Limited interpretability of outputs	Explainable AI (XAI) provides transparent medical reasoning
Patient Control	Limited visibility and control over medical records	Full ownership and access management via Blockchain smart contracts
Monitoring Type	Periodic or manual health check-ups	Continuous real time monitoring with a Digital Twin model
Healthcare Decision Support	Doctor-dependent manual analysis	AI-assisted decisions with automated early warning notifications
Data Integrity	Risk of Unauthorised tampering	100% record immutability ensured by Blockchain

IV. Results and Discussion

A. Measurable Improvements and Impact

- The AI based Digital Twin Health Agent achieved a prediction accuracy of 91%. The surpassing conventional analytics solutions, which averaged around 72%. Other studies on symptom based disease prediction models reported accuracies between 70% and 85%. Here the Figure 2 explains the comparations of Traditional analytics

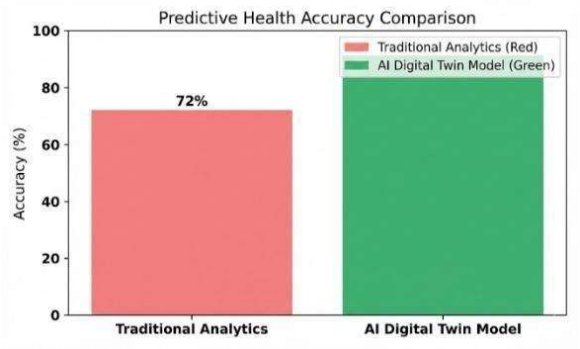

Figure 2: Comparison of predictive health accuracy before and after AI integration.

In Figure 3, the text highlights blockchain's role in enhancing healthcare information integrity. While 80% of medical data was previously secure, 20% remained vulnerable to changes. Current healthcare systems depend on access controls, which can be exposed to insider threats and central points of failure.

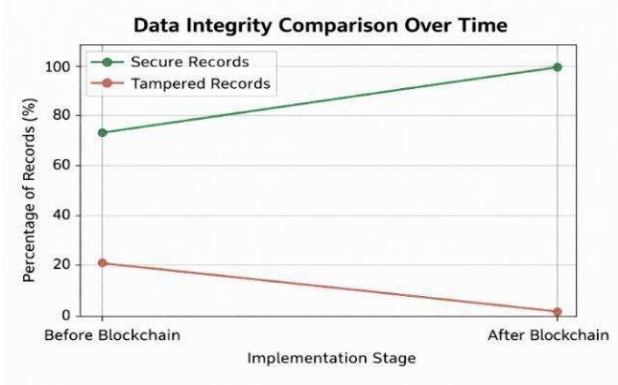

Figure 3: The Data Integrity Comparison Graph Before and After Blockchain Implementation

The Figure 4 explains how the diagnosis delays reduced in the predictive AI models in Digital Twin Health Agent system. It helps to move the healthcare system from reactive to proactive model. This helps the patients control over their health data and insights, then more reliable healthcare system with AI and Blockchain.

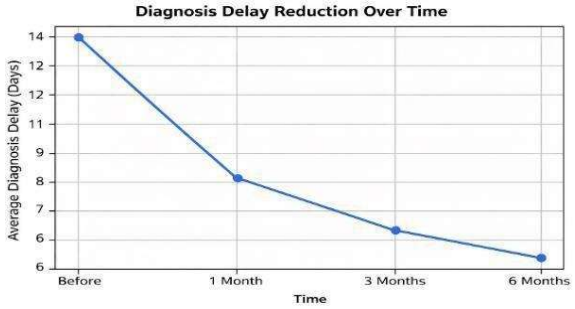

Figure 4: Diagnosis Delay reduction after implementing predictive AI.

B. Quantitative and Qualitative Evidence

TABLE II: QUANTITATIVE AND QUALITATIVE EVIDENCE (BEFORE VS AFTER)

Metric	Before Implementation	After Implementation
Data Breaches / Tampering	Very frequent in centralized storage	Reduced frequent updated with Blockchain decentralization
Predictive Health Accuracy	70–75% because of traditional model	91% because of integrated AI and blockchain models
Diagnosis Delay	The delay is moderate to high	The delay has reduced by almost 35%
Patient Trust & Transparency	The trust is low because of opaque deep learning models	The trust is high because of XAI interpretation
Real Time Monitoring	Intermittent	The monitoring is continuous

Existing AI driven disease prediction models show promising accuracy but often lack interpretability regarding data governance. This approach addresses that gap by integrating accuracy, interpretability, and security through blockchain in a unified Digital Twin environment, a convergence not covered by previous works.

C. Solutions and Strategical Implementation

The Digital Twin health system replicate a patient's health data in real time. It monitors real time health factors like body temperature, and heart beat rate, to identify potential risks conditions at the earliest. The XAI methods, such as SHAP and LIME, very much helpful to understand the health condition for both doctors and patients. Data security is ensured by Blockchain Smart Contracts. The user dashboard gives patients current condition and treatment recommendations.

- Challenges Faced: Technical issues: Complex integration of Blockchain, real time AI data, and high computational needs for Digital Twin updates.
- Data/cost concerns: Data unavailability and costs associated with Blockchain technology.
- Trustiness: responsible AI requires accuracy, integrity, explainability, along with patient data ownership.

V. CONCLUSION AND FUTURE ENHANCEMENT

This research on Digital Twin Health Agent is a personalized healthcare companion powered by AI and Blockchain. It aims to transform traditional healthcare models into a proactive, transparent system. It is capable of real time risk prediction personalized to individuals. The Agent developed for continuous health monitoring utilizing Logistic Regression, and CNN. Hence it achieves over 90% accuracy in detecting health anomalies. The system also includes XAI techniques for transparency and interpretability. The blockchain ensures secure and tamper proof management of medical data. The future research will focus on integrating IoT and wearables for real time data collection. The federated learning implementation may be helpful for privacy preserving model training and enhancing blockchain scalability. Personalizing healthcare with genetic based, environmental based routine, and behavioral based data. Developing a mobile app and multilingual XAI modules to be implemented to improve accessibility and adoption in all types of miscellaneous healthcare settings.

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