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HealthSureChain:A Smart Contract-Based Decentralized Framework for Healthcare Insurance Claim Processing and Predictive Fund Allocation

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ABSTRACT: ***The traditional process of handling health insurance claims involves centralized systems and manual verification processes that are associated with high chances of delays, lack of transparency, and even fraud. Additionally, the lack of a secure and tamper-proof data sharing process between insurance companies, hospitals, and patients. This paper proposes a blockchain technology-based solution for the efficient management of health insurance claims, which is named HealthSureChainand is developed as a decentralized application on the permissioned Ethereum blockchain technology. Smart contract is used to automate the process of policy registration, premium payment, claims submission, eligibility checking, and claims approval. Medical records and patient data are stored in a secure manner through IPFS storage, while the hash of the data is stored on the blockchain for checking purposes. A predictive analytics component has been used to determine the future reserve fund requirements.***
Keywords: Blockchain, Decentralized Applications (DApp), Health Insurance Claim Management System, Predictive Analytics.

I. INTRODUCTION

Healthcare insurance firms offer coverage against medical costs. A health insurance claim refers to a request for payment filed either by a hospital or the insured person to the insurance firm. Nevertheless, the present approaches involve the use of centralized infrastructure and verification that makes the process inefficient, lengthy, opaque, and prone to fraud . Centralized systems are also highly susceptible to failure and hacking Conventional insurance schemes operate under a trust model among patients, hospitals, and insurers; however, such insurance schemes are prone to fraudulent activities, errors, and lengthy processes, which lead to financial loss and higher premiums. Besides, the use of centralized storage mechanisms for patient information poses great risks to privacy and security.The allocation process for reserve funds is based mostly on policies, which leads to either the excessive use or insufficient use of funds. In addition, the lack of a tamper-proof unified identification mechanism makes the system susceptible to fraud. Finally, inadequate interaction between the different parties results in delayed processing of claims .To solve these problems, we present HealthSureChain, an insurance claims processing platform developed as a decentralized application running on a permissioned Ethereum blockchain. HealthSureChain allows registering the parties involved in the processing, subscribing them to a policy, and automatically verifying claims using smart contracts. Records of the medical condition of patients are stored using the IPFS protocol, while only their hash value remains on the blockchain. Unlike other platforms, which use purely cryptocurrency for payments, HealthSureChain provides the ability to pay for claims using blockchain validation combined with regular banking institutions. Once the claim is processed, its funds are sent to the corresponding bank accounts, and this transaction is recorded on the blockchain for auditing purposes. Moreover, there is a module for predicting future needs regarding the reserve funds based on past experience.

II. PROBLEM STATEMENT

In conventional health insurance, the involvement of third-party administration is one of the factors that lead to wastage of time and money in the process of claim submission. Centralized storage of medical records makes them vulnerable to any act of fraud. Patient identification can be bypassed easily through manual verification by the fraudster, making it easy for them to commit acts of fraud. Unless patients have validated their details and ensured that their information is updated, fraudsters can easily submit fraudulent claims.

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III. LITERATURE REVIEW

Alnuaimi et al.[1] introduced a private Ethereum-based framework for prescription drug insurance claims using smart contracts and IPFS. Namitha T. S. et al.[2] have proposed a blockchain-based health insurance system using smart contracts and IPFS for efficient handling of insurance claims and prevention of fraudulent activities. Elhence et al [3] developed a framework using blockchain and machine learning to efficiently verify insurance claims and compute premiums using personalized premium prediction and risk-based premium rebate computation. Blockchain based health insurance systems using smart contracts have been proposed to ensure the secure, transparent, and immutable handling of insurance claims and other stakeholder related activities[4][5][6][7]. Zahid et al. [8] presented a health insurance model with a blockchain-based architecture, along with IPFS for decentralized storage of health records and permission based access control. Karmakar et al.[9] proposed a smart contract-based blockchain system called ChainSure, which uses the TOPSIS technique to recommend health insurance policies based on user preferences. Pragatheeswari et al. [10] utilized unsupervised machine learning clustering algorithms for clustering health insurance claim amounts based on insurance charges and hospitalization costs.

IV. SYSTEM ARCHITECTURE

This paper proposes HealthSureChain, a blockchain-enabled health insurance claim processing framework integrated with predictive analytics for intelligent fund allocation. The system is built on a permissioned Ethereum blockchain, where verified stakeholders communicate via a DApp. HealthSureChain uses smart contracts for registration and role control, policy management, claim processing, IPFS-based medical document linking, and fund allocation notifications.

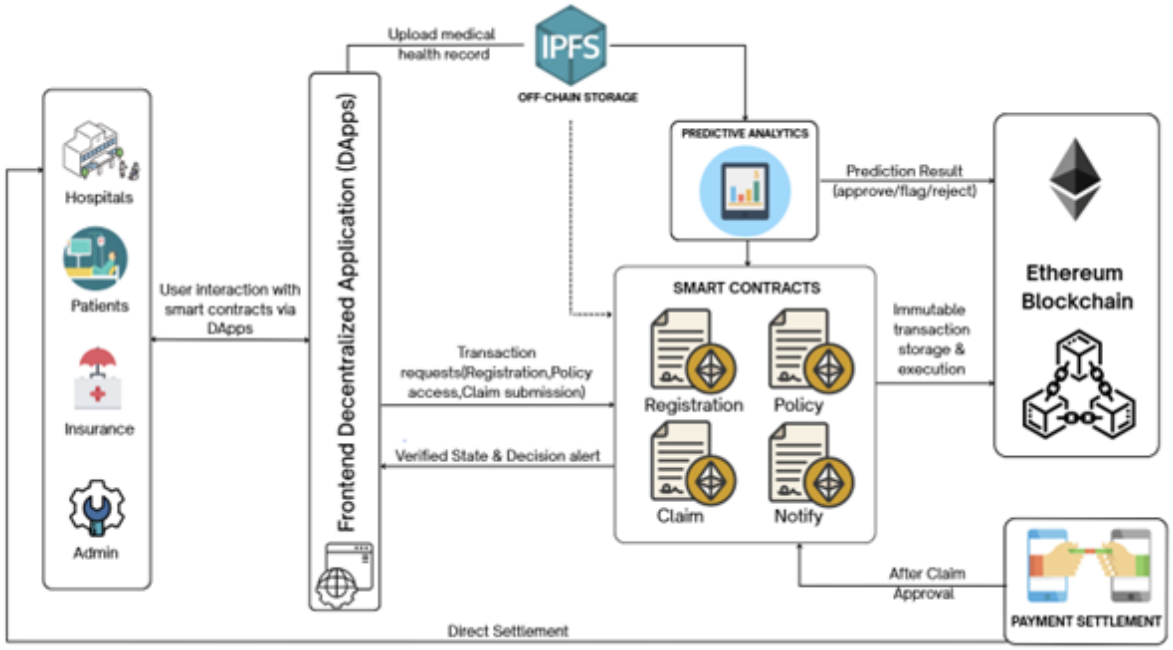

Figure 1. Blockchain-based Health Insurance Architecture

A. *Overview*

HealthSureChain works in the context of four roles: Regulatory Authority, Patient, Hospital, and Insurance Company, all of which are represented by Ethereum addresses having role-based access to the platform. Blockchain is at the core of this structure, which allows each operation such as registering patients, subscribing to insurance policies, paying premiums, making pre-authorizations, submitting claims, and making payments as a result, to be saved into the blockchain in a new block on the Ethereum network. Every transaction is signed using ECDSA (Elliptic Curve Digital Signature Algorithm), which means that only those who have accesscan carry out transactions on the platform. HealthSureChain uses a five-contract smart contract architecture: Registration and Role Management Contract that allows participants' access control, Policy Management Contract that manages the metadata of insurance policies and saves IPFS document links in it, Claim Processing Contract that processes claims in an automated way, from submission till payment, IPFS Document Registry Contract which is a mapping of claims ID and corresponding medical document CID from IPFS, and Fund Allocation Contract that saves results of predictive analysis performed on the blockchain itself.

For scalability and computing requirements, the system incorporates off-chain mechanisms along with the blockchain layer. The medical documents, such as prescriptions, medical bills, diagnosis, and discharge reports, are stored in an encrypted form on the IPFS network, with their CID stored on the blockchain to guarantee authenticity and avoid any manipulation. A Flask-based intermediary is used as the trusted middleman connecting the blockchain and off-chain layers. It listens for events emitted from smart contracts, retrieves claim and policy information, fetches IPFS documents, and provides the output back to the blockchain. The claim submission process for the HealthSureChain platform adheres to a certain pattern: the insurance company enrolls all stakeholders and publishes policy information on-chain, the hospitals upload medical files to IPFS and file claims by referencing their CID, smart contracts carry out the eligibility check in an automated manner, and finally, the insurance company processes the claims and either accepts or rejects them using the DApp.

A machine-learning-based module for predictive analytics to help in efficient fund allocation is part of the proposed platform. Using XGBoost Regression algorithm, a model will be created from historical claim data monthly and used to predict reserves needed for 12 months of 2026, including seasonal variations patterns to increase accuracy. The reserve for each month will be obtained by summing up the predicted claims and adding an IBNR factor (15.5%) to RBNS factor (26.3%), plus a risk factor of 10%, to ensure that the insurer has enough reserves to cover all approved claims. A rolling forecast approach is used where the model will be retrained monthly using updated data as actual claims arise, thus gradually increasing the accuracy of the predictions throughout the year. Weekly monitoring of actual expenses incurred on claims compared to predictions can be done to detect any possible depletion of reserves and alert accordingly. Predictions, however, will be done using the off-chain middleware due to the inability of the smart contract to utilize machine learning.

B. Smart Contract Design

The HealthSureChain system uses a modular smart contract design in which multiple functional smart contracts perform different operations to ensure maximum flexibility in updating the application logic.

1) Registration and Role Management Contract

The smart contract handles the access permissions for insurers, hospitals, and patients. The Regulatory Authority registers verified participants and assigns roles to ensure authorized interaction.

2) Policy Management Contract

The smart contract stores vital policy information that is essential for verifying the policy on the HealthSureChain system. Minimum information about the policy is recorded on the blockchain to ensure maximum security. The policy documents are recorded off the blockchain in an encrypted manner. However, the link to the document on the IPFS is recorded on the blockchain.

3) Claim Processing Contract

The smart contract takes care of the entire process of claims from the beginning of the claim to the end of the claim. Every step in the claim process is recorded on the blockchain with timestamps to ensure maximum transparency.

4) IPFS Document Registry Contract

The documents relating to the patient, such as the medical reports and invoices, are recorded on the IPFS. This smart contract maps claim IDs to their respective IPFS CID.

5) Fund Allocation and Notification Contract

This is a contract that will store off-chain prediction results, which include predicted monthly claim expenditures and fund allocation. This is done through predictive analytics, which is carried out using an XGBoost regression model to predict the expected claims. This is then computedas:

$$R_m = \hat{C}_m + z_\alpha \sigma_m \quad (1)$$

where $\hat{C}_m$represents predicted claim expenditure, $\sigma_m$denotes historical claim volatility, and $z_\alpha$is the statistical confidence factor. This provides risk-adjusted reserve planning rather than static buffering.

To monitor financial stability, a reserve depletion ratio is defined as:

$$DR_m = \frac{A_m}{R_m} \quad (2)$$

where $A_m$is the actual payout. If $DR_m > \theta$, an early warning alert is triggered to prevent reserve exhaustion. Surplus reserves may be reallocated within predefined safety constraints to optimize liquidity distribution.

C. Security and Privacy

Integrity is assured through the use of a blockchain record of all claims, which cannot be altered or manipulated. Traceability is assured through the use of time-stamped transactions that can be audited.

Confidentiality is ensured by using a private Ethereum network, thus avoiding unauthorized access. The medical documents are stored off the chain as encrypted data, with the CID stored on the chain to ensure privacy. The reduction of fraud is ensured by using unique claim identifiers to avoid duplicate claims.

V. RESULT

The HealthSureChain system was successfully implemented and validated on a private Ethereum blockchain network. The HealthSureChain system is able to successfully demonstrate that key aspects of a traditional health insurance system are able to be carried out on a blockchain-based smart contract without the need for a centralized intermediary. The patients were able to successfully complete a multi-step verification process via a KYC verification process that involved AI-based face recognition using face-api.js and subscribe to available policies via a secure real-time payment process. The patients are also able to track their policy details and payment history via a real-time dashboard on the blockchain platform.

The patients are also able to submit claims via a cashless process by uploading relevant documents such as discharge summaries and lab reports via IPFS, and the relevant CID is stored immutably on the blockchain via the smart contract. The insurer is able to review the claims via the DApp dashboard and approve or reject them after verification. The insurer also automatically initiates a blockchain-based fund transfer from its reserve fund pool to the hospital after approving a claim. The insurer dashboard successfully displayed statistics regarding the number of subscribers, active policies, claims made, claims settled, and the total amount of premium collected, while the smart contracts successfully operated as expected with verified changes and access control.Additionally, the system will have a fund allocation component based on machine learning, which will analyze the pattern of claims made to facilitate efficient planning and stability.

Table 1. Evaluation Metrics for Initial and Rolling Forecast Models

Model Stage	Model	R^2	MAPE	MAE
Initial Reserve Allocation	XG Boost	0.94	3.55%	₹74,446
Roll Forecasting		0.95	3.49%	₹66,037

Table 1 presents the performance metrics of the XGBoost model at two stages: initial reserve allocation and rolling forecast after incremental retraining.

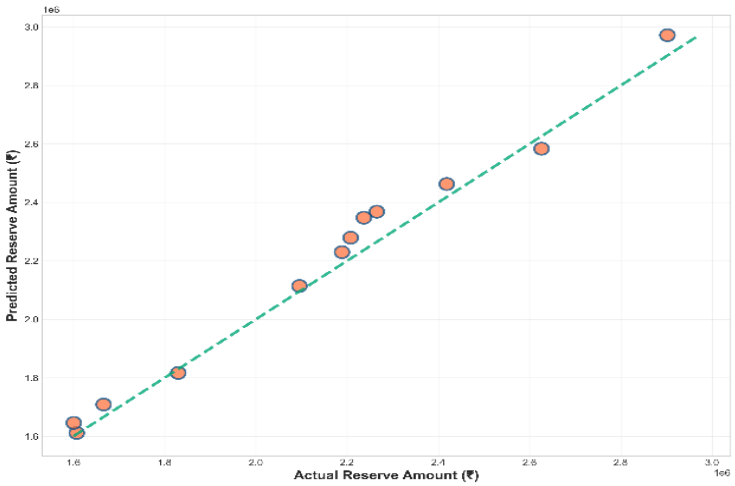

Figure 2.Actual vs Predicted Reserve Amounts

The scatter plot in Figure 3 shows the correlation between actual and predicted reserve amounts. The diagonal line represents perfect prediction. Points clustering near the line demonstrate strong model accuracy with minimal prediction error.

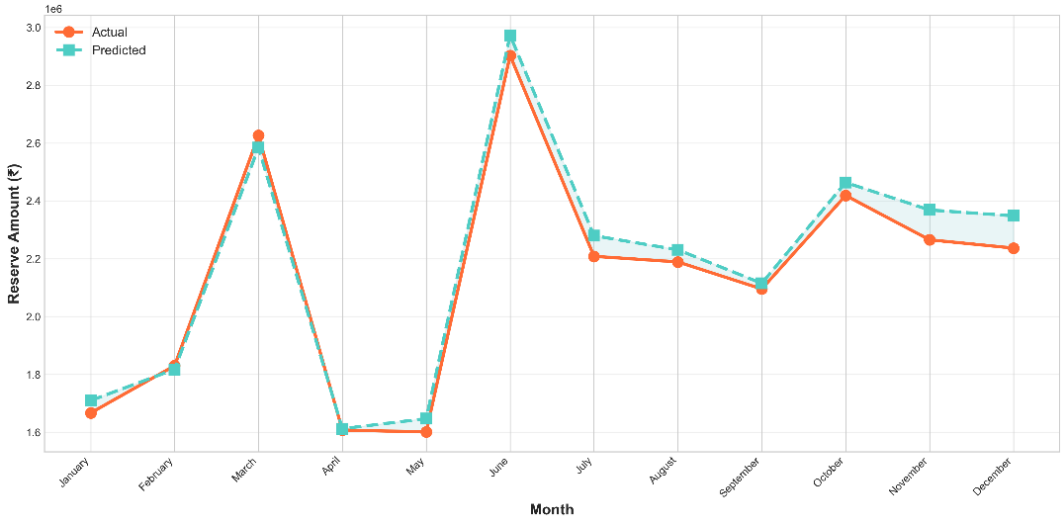

Figure 3. Time Series: Actual vs Predicted Monthly Reserves

The graph shown in Figure 3displays the temporal pattern of actual versus predicted monthly reserve amounts, highlighting the model's performance over the time period.

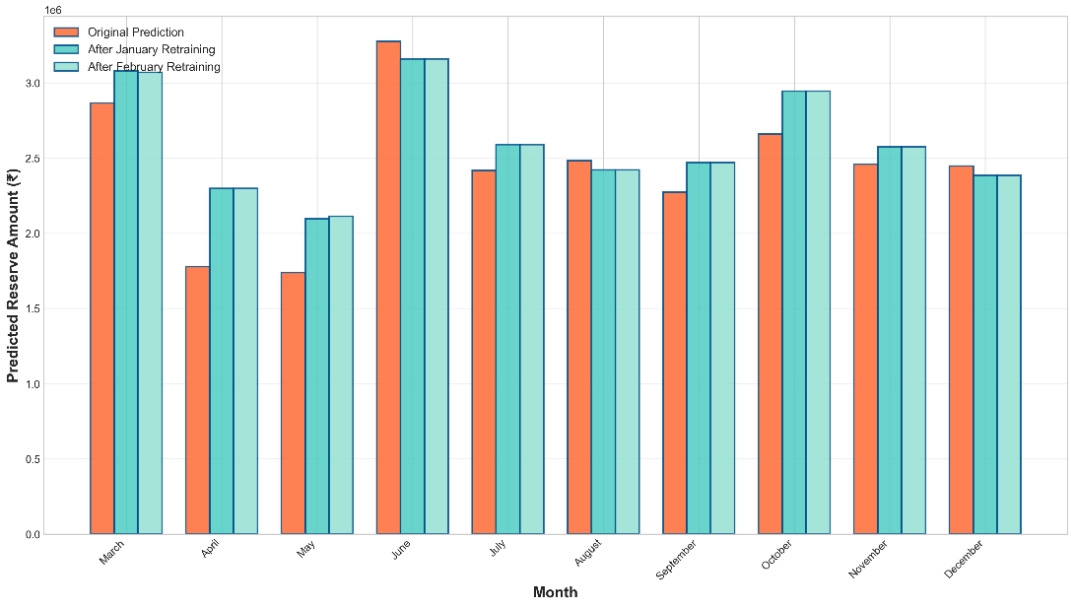

Figure 4. Rolling Forecast: Prediction Changes After Incremental Retraining

The visualization in Figure 4 illustrates how predictions evolve after incremental retraining with new monthly data, demonstrating the adaptive forecasting approach.

VI. CONCLUSION

In this paper, a new health insurance claim management system called HealthSureChain was introduced, which uses a blockchain-based system to promote transparency, security, automation, and economic efficiency. In this system, a permissioned Ethereum network is used to execute a series of smart contracts that are used to automate participant registration, policy management, claim verification, and settlement. In order to overcome the problem of storage that exists with the blockchain, a new method of storing the encrypted medical information using the IPFS has been proposed, and a cryptographic hash has been stored on the blockchain. In addition, a predictive reserve management module using XGBoost regression is used to predict monthly claim expenses and determine the reserve buffers. HealthSureChain provides a secure, scalable, and financially intelligent solution for decentralized health insurance claim management.

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VII. FUTURE WORK

Further development will revolve around improving the prediction component by implementing state-of-the-art deep learning approaches such as Long Short-Term Memory (LSTM) and Transformer models, as well as probabilistic forecasting to improve reserve forecasting. Scaling issues will be addressed by using Layer 2 scaling methods as well as enterprise blockchain frameworks like Hyperledger Fabric. Interoperability will also be investigated in order to provide the integration of data from healthcare systems and standards. The deployment of upgradable smart contracts and decentralized governance systems will enable further improvement of the system without compromising its security and blockchain integrity.

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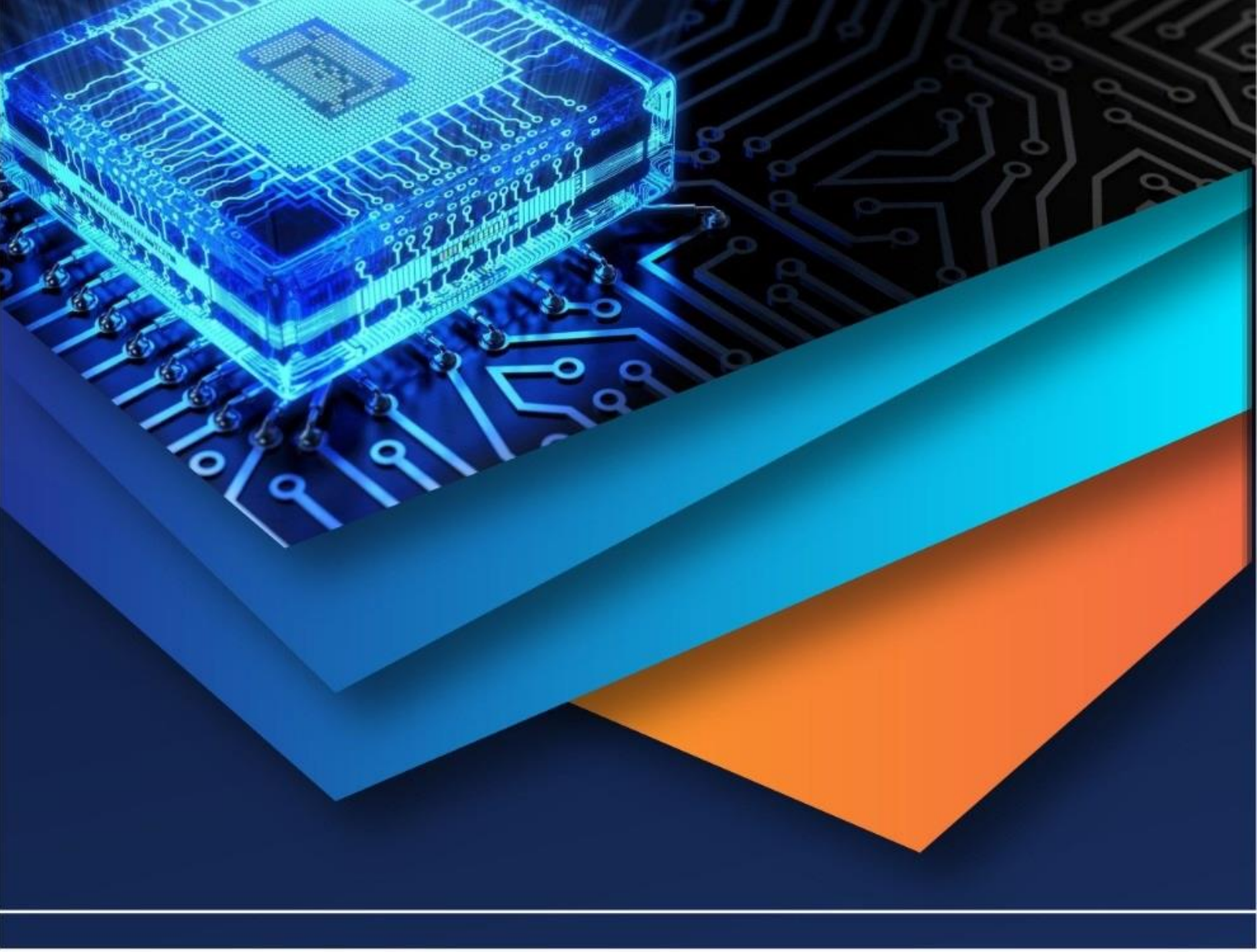

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