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Dental Data Management Using Blockchain Technology

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Abstract: "Biometrics" refers to identification of humans by their characteristics or traits. Dental biometrics is the technology used in forensic dentistry to identify individuals based on their dental radiographs. Dental features have proved useful for identification purposes [4]. The proposed method works with three main processing steps: [1] extraction of features by segmentation of dental works (crowns, fillings, and bridges) using mathematical morphological operations followed by thresholding; [2] generation of the dental code based on the distance between neighboring dental works and the angle at which the dental works are aligned; and [3] matching of the dental code of the panoramic radiographs with the codes in the database [4].Additionally,thesystemincorporates motion detection to address human-animal conflicts in agricultural fields. Using background subtraction and object classification (via YOLO or similar models), the system detects and classifies intruders (e.g., animals or humans) and sends real-time alerts to farm owners andofficials via Telegram notifications.

Because the healthcare sector is large and ever-growing, blockchain technology offers many benefits. Researchers advocate using blockchain and smart contracts to improve dental care delivery due to their numerous advantages [3]. Blockchain ensures tamper-proof and authorized access to patient data, enabling secure interoperability between systems and facilitating seamless data exchange [2]. Patient dental and medical data, often scattered across different organizations, leads to poor care coordination; blockchain addresses this issue effectively. Efficient data management is critical in modern dentistry, ensuring the accuracy and accessibility of records for better care [1]. This paper also discusses how blockchain fits alongside other emerging technologies, promoting a digital revolution in dentistry [6].

I. INTRODUCTION

Dental records play a critical role in modern healthcare, as oral health is closely interconnected with the overall well-being of the human body. There is growing evidence that dental infections are linked to systemic conditions such as gut health issues, thyroid dysfunctions, cardiovascular diseases, lung infections, and chronic kidney disorders [10]. In particular, bacteria from dental infections can enter the bloodstream and affect distant organs, with studies revealing traces of oral bacteria in atherosclerotic plaques and respiratory infections such as aspiration pneumonia. Similarly, chronic periodontitis has been associated with increased risk for chronic kidney disease due to the body's inflammatory response to oral pathogens.

With such strong interconnections between dental and general health, managing dental records securely, accurately, and efficiently is essential. Traditional paper-based or outdated digital systems have proven inadequate in safeguarding sensitive patient data.

Blockchain technology offers a promising approach to address these issues. As a decentralized and tamper-proof ledger, blockchain ensures data immutability, integrity, and transparency without requiring a third-party intermediary. Its ability to securely manage access through smart contracts and cryptographic techniques makes it ideal for storing sensitive medical records, including dental data [6]. Blockchain also enables interoperability across platforms, allowing seamless data sharing among dental care providers, insurance companies, and laboratories [4][5].

On the other hand, Machine Learning (ML) is transforming dental diagnostics and data handling. ML techniques can be used for image enhancement, feature extraction, anomaly detection, and classification based on dental radiographs. These capabilities enable automated identification of dental conditions, reduce diagnostic errors, and support streamlined workflows in dental practices. ML can also compress and store X-ray images more efficiently, reducing both storage costs and space requirements. Moreover, centralized databases powered by ML can support research efforts and enhance treatment outcomes.

Despite the potential, the integration of blockchain and ML into dental data management remains limited. Barriers include lack of awareness, technical constraints, regulatory challenges, and insufficient expertise in emerging technologies among dental professionals [6]. Addressing these challenges requires a systematic approach to evaluate current practices, design secure and scalable architectures, and demonstrate practical viability.

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This paper proposes an integrated system combining blockchain for secure record management and machine learning for biometric identification using dental X-rays. The objective is to enhance the privacy, interoperability, and intelligence of dental healthcare systems, ultimately improving patient care across the sector.

II. LITERATURE REVIEW

The integration of emerging technologies like blockchain and machine learning into dental healthcare has attracted significant academic attention in recent years. The literature emphasizes the need for secure, interoperable, and intelligent systems to manage the rapidly growing volume of dental data, especially in digital formats such as panoramic X-rays.

Mettler (2016) highlighted blockchain's transformative potential in healthcare systems, particularly in enhancing data transparency, traceability, and security [9]. Liu et al. introduced a blockchain-based system specifically tailored for dental applications, where encrypted metadata of X-rays is stored on-chain while the actual images are managed off-chain to maintain performance and compliance with healthcare regulations.

Machine learning techniques, especially deep learning models like Convolutional Neural Networks (CNNs), have proven effective in dental diagnostics. These models can detect and classify oral diseases directly from X-ray images with high accuracy [10]. However, the fusion of ML with blockchain technology is a more recent innovation. Zhang et al. proposed a hybrid model where ML performs automated diagnostics while blockchain ensures secure access, storage, and sharing of diagnostic outcomes.

Dentacoin represents one of the first large-scale attempts at deploying blockchain in dentistry. It introduced smart contract-based services like Dentacoin Assurance and Dentacare, enabling peer-to-peer insurance and incentivized dental care. Platforms such as Dentistry.AI and Xray Vault have further demonstrated the feasibility of combining AI with decentralized storage to assist in diagnostics and record management [12].

Despite these innovations, challenges remain. These include issues of scalability, latency in real-time ML inference, and interoperability with existing dental systems. Recent work has begun exploring federated learning and smart contract automation to mitigate these concerns and to create more robust, patient-centric ecosystems.

In summary, the literature underscores that combining blockchain's immutability and access control with ML's intelligent analysis capabilities can lead to significant advancements in dental data management. However, to achieve clinical adoption, future systems must prioritize ease of integration, data privacy, and regulatory compliance.

III. PROPOSED SYSTEM

1) The proposed system includes six modules. The system starts with the acquisition of dental X-ray images, which are digitally collected from the user. In the next stage of the research image was subjected to a pre-processing stage. Making use of it the size and complexity of the image are reduced.
2) The records are encrypted and stored on a blockchain, ensuring data security and integrity.
3) Feature extraction is performed to identify unique dental characteristics from the images.
4) A biometric identification process uses these features to verify the user's identity.
5) A machine learning model processes the features for classification, and the output is securely linked back to the blockchain network

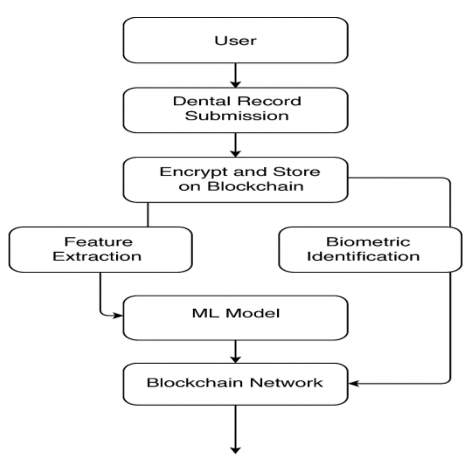

Fig: Proposed System

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The design uses a combination of non-technical and moderately technical language to make it understandable to both technical stakeholders and administrative users. It highlights how each module—such as user input, blockchain storage, feature extraction, biometric identification, and ML-based classification—works in coordination to ensure secure and intelligent dental data processing.
The proposed system has the following for dental data management using blockchain

- User Submission: The process begins with the user (e.g., a dental clinic or authorized healthcare) submitting digital dental records such as panoramic radiographs or dental X-ray images. These records serve as the primary biometric input for the system.
- Dental Record Encryption and Storage:Upon submission, the dental records are encrypted and securely stored on the blockchain. This ensures tamper-proof and traceable storage, enabling data integrity, authenticity, and availability to authorized users only
- Feature Extraction:The dental images undergo feature extraction where dental traits such as crowns, fillings, bridges, and alignment are identified. This involves isolating and encoding features that are unique to each individual's dental structure.
- Comparative Analysis of Distance Metrics
  In the process of matching dental features for biometric identification, choosing an appropriate distance metric is crucial. We evaluated three popular metrics—Euclidean, Manhattan, and Minkowski distances—for their performance in comparing extracted feature vectors. The Euclidean distance, being sensitive to large differences, works well for precise geometric comparisons. The Manhattan distance is more robust to outliers and better suited for cases with noise or less variation in spatial arrangement. Minkowski distance provides a generalization of both, allowing adaptability by tuning the parameter p.
  The table below summarizes the comparative characteristics of these metrics in the context of dental biometrics:

Metrics	Total Images	Correctly Identified Images	Accuracy
Euclidean	310	300	96.83%
Manhattan	310	297	95.76%
Minkowski	310	288	92.73%

- Biometric Identification:Using the extracted features, a biometric identification process takes place. The goal is to match the current dental code to the stored records, thereby uniquely identifying a person based on their dental image.
- ML – Model Preprocessing:The encoded dental features are then processed by a Machine Learning (ML) model, which has been trained to analyze the spatial and structural configuration of dental elements. This model assists in classification and validation of the biometric match, enhancing accuracy and reducing false positives.
- Blockchain Network Integration: Once the identity is validated, the corresponding dental and medical records are retrieved securely from the blockchain network. The system allows only authenticated and verified access using smart contracts to maintain privacy and control over data.

IV. SYSTEM ARCHITECTURE

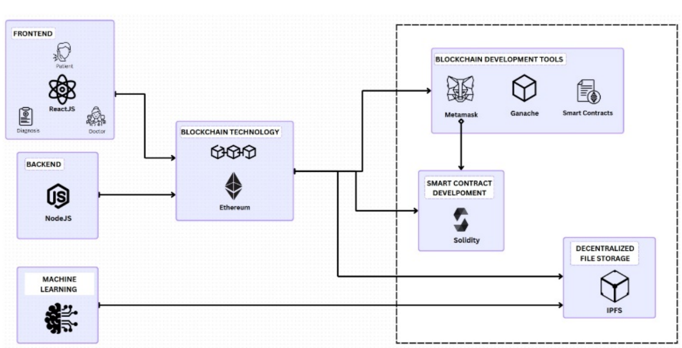

Fig:SystemArchitectureofdental data management

The above system architecture illustrates a decentralized healthcare framework that integrates blockchain technology, machine learning, and decentralized storage to ensure secure, transparent, and intelligent medical data management. Blockchain technology is implemented using the Ethereum platform to ensure tamper-proof data records. Smart contracts, developed in Solidity, automate access control and data validation mechanisms. These contracts are deployed and tested using tools such as Ganache, Metamask, and integrated with the Ethereum blockchain through blockchain development tools.

The frontend, developed using ReactJS, enables interaction for three key user roles: Patients, Doctors, and Diagnosis modules. This interface facilitates user-friendly access to medical records and diagnostic reports. The backend, built with NodeJS, handles API logic, integrates with smart contracts, and communicates with the blockchainlayer.

At the core, Ethereum blockchain is used to provide immutability, data transparency, and secure access control through smart contracts written in Solidity. These contracts govern data access permissions and transactions. Development and deployment are supported using blockchain development tools such as Ganache, Metamask, and Truffle.

The Machine Learning (ML) module is integrated to enhance diagnostic capabilities and assist in data-driven decision-making. It processes patient data to generate predictions or classifications (e.g., disease risk or diagnosis outcomes). The results of these ML models are stored securely using IPFS (InterPlanetary File System), a decentralized file storage system, ensuring both accessibility and tamper-resistance.

This hybrid system leverages the intelligence of ML, the security of blockchain, and the efficiency of decentralized storage, making it highly suitable for modern healthcare environments demanding privacy, scalability, and intelligent automation.

V. METHODOLOGY

1) Blockchain-based Data Storage: Blockchain serves as a secure and decentralized ledger for storing dental health records, including X-ray image references. Instead of saving sensitive patient data directly, the system encrypts the X-ray images and generates their cryptographic hashes using SHA-256. These hashes are stored in a blockchain to ensure immutability, traceability, and tamper-resistance.

Each transaction on the blockchain represents a new or updated health record, containing:

- A unique patient identifier
- A reference to the encrypted X-ray stored in a secure database
- The hash of the X-ray for verification
- Timestamp and transaction metadata

This ensures any modification to the image or record is immediately detectable. The decentralized nature of blockchain also removes dependency on a single server, making the system resilient to attacks and enhancing trust among patients and institutions.

2) Feature Extraction and X-ray Matching from Encrypted Data: To identify a person from an uploaded dental X-ray image, the system performs the following steps:

- Decryption and Feature Extraction: When a query image is uploaded, it is decrypted securely in-memory and processed to extract features using image segmentation and morphological operations. These features include tooth positions, inter-tooth distances, and angular orientation of dental works like crowns or fillings.
- Hash Validation: Before proceeding with the comparison, the extracted image is hashed, and the resulting value is matched against existing hashes stored on the blockchain to verify authenticity and integrity.
- Matching via Euclidean Distance: The extracted feature vector is then compared against the database of stored vectors (from previously uploaded X-rays) using Euclidean distance. A threshold-based comparison identifies the best match, linking the input image with the stored record.

This integration of blockchain for secure record tracking and machine learning for image analysis enables a novel, privacy-preserving identification system for dental biometrics.

3) Data Acquisition and Preprocessing: A curated dataset of panoramic dental X-rays (OPGs) from 316 patients was used. These images were anonymized and de-identified to preserve patient privacy. Preprocessing steps included grayscale conversion, contrast enhancement, and noise reduction filtering to ensure image clarity for subsequent operations.

Fig: Panoramic dental X-ray

4) Dental Code Generation:To ensure reliable patient identification and clinical support:
- The ML pipeline begins with segmentation of dental works (DWs) such as crowns, fillings, and bridges using morphological operations and thresholding.
- A unique Dental Code (DC) is generated using features like distance, alignment angle, and center of mass between DWs[9].
- These codes are then stored off-chain in a secure, indexed database, while their hashed references are recorded on the blockchain.

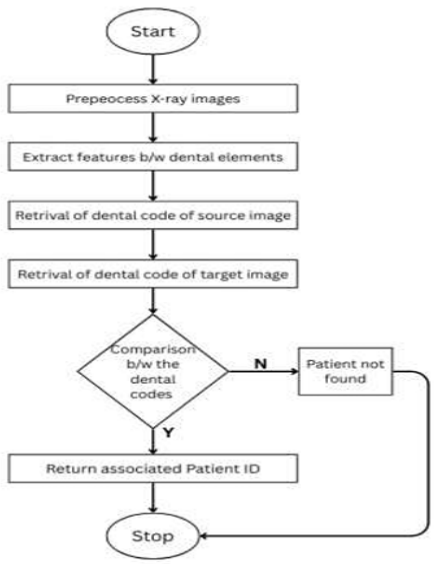

Fig: Diagram showing feature extraction

5) Blockchain Integration: Blockchain, specifically the Ethereum network, is employed to:
- Store immutable hashes of X-ray data and diagnostic records.
- Implement smart contracts (via Solidity) for access control, patient consent management, and transaction logging [2].
- Enable patient-centric control, where individuals can grant/revoke access to dental records.

Smart contracts ensure only authorized personnel can access or modify patient data. This approach leverages MetaMask for user authentication and Ganache for local blockchain simulation and testing [4].

6) Off-Chain Storage using IPFS: Due to the large size of medical images, data is stored off-chain in Inter-Planetary File System (IPFS):
- The Content Identifier (CID) of each image is stored on the blockchain.
- This ensures that even though the bulk data resides off-chain, its authenticity and integrity are verifiable [1].

7) System Interoperability and User Interface Integration:The system is designed for interoperability with other clinics and healthcare systems:
- A user-friendly ReactJS frontend allows patients and doctors to upload, access, and manage dental records.
- NodeJS backend handles API communication, blockchain interaction, and database operations.

- This modular architecture ensures future scalability, easy integration with health networks, and cross-platform compatibility [5].

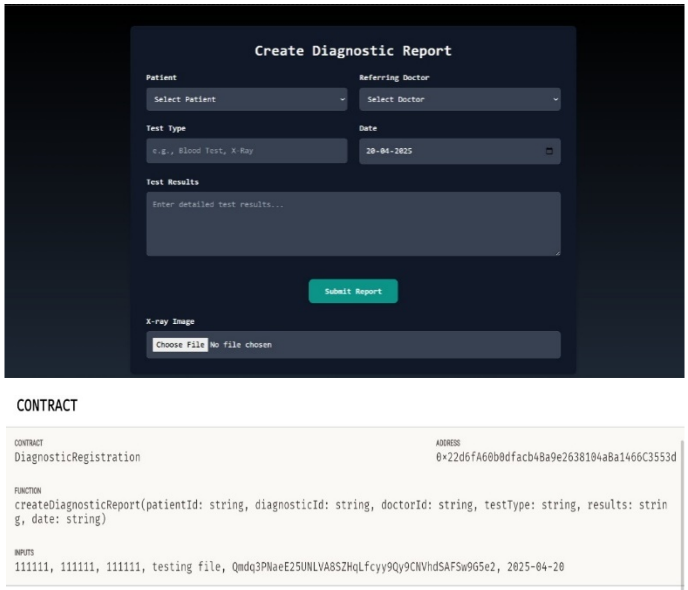

Fig: Diagnostic Form

8) Consent and Access Management: The system adopts a patient-centric consent model, leveraging blockchain technology to manage secure and traceable access to dental records. Patients retain full ownership of their data and can grant, revoke, or modify access permissions in real time through an intuitive web interface [8].

- Patients retain full control over who accesses their dental records.
- Access requests are validated through smart contracts, with cryptographic logging on-chain.
- Audit trails provide transparency for every data access event.

Algorithm Flow:The proposed system follows a streamlined and modular algorithmic pipeline to manage dental records securely and efficiently, integrating blockchain and IPFS-based storage mechanisms.

The flow begins when a patient uploads a panoramic dental X-ray via the frontend interface. The system preprocesses the image and performs feature extraction, generating a structured Dental Code (DC) based on geometric patterns observed in crowns, bridges, and fillings [7].

Metric	Observation
Data upload time (IPFS)	~3–5 seconds (depending on image size)
Smart contract execution time	< 5 seconds (local Ganache network)
Access approval latency	Real-time upon MetaMask confirmation
User roles tested	Patients, Doctors (simulated scenarios)

Once the data is processed, it is uploaded to IPFS, and the resulting Content Identifier (CID) is recorded on the Ethereum blockchain via a smart contract. The CID acts as a permanent reference to the dental record and is tied to the patient's identity and consent settings.

When a practitioner requests access, the smart contract checks for patient approval. If permission is granted, the CID is retrieved from the blockchain, and the dental record is fetched securely from IPFS for viewing or updating.

This algorithm ensures:

- Secure data storage through decentralized architecture.
- Immutable and traceable access using blockchain logs.
- Dynamic, real-time consent management governed by smart contracts.

The complete flow demonstrates how modern technologies can be effectively orchestrated to maintain both data privacy and clinical usability in dental record management.

VI. RESULT

The proposed system was successfully implemented as a working prototype that demonstrates secure, decentralized, and patient-controlled dental data management using blockchain and IPFS. A combination of frontend, backend, and smart contract development was validated through real-time interactions between patients and practitioners in a simulated environment.

1) SmartContract Execution and IPFS Integration:Smart contracts were deployed on a local Ethereum network using Ganache, and all blockchain interactions were facilitated through MetaMask. When a dental record (X-ray) is uploaded, it is processed and stored on IPFS, which returns a Content Identifier (CID). The CID is then logged on the blockchain via a Solidity smart contract.

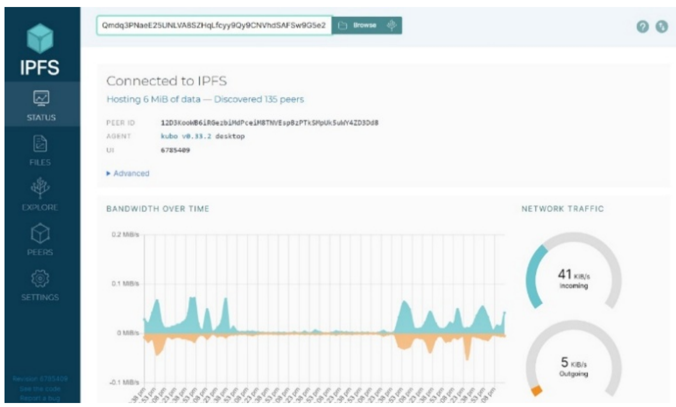

Fig:Fetching IPFS hash of X-ray file

2) Web Application Interface:The web application interface was developed using ReactJS for the frontend and NodeJS for backend services. Two main interfaces were built:

- Patient Dashboard: Enables users to upload X-rays, grant/revoke doctor access, and view their record history.
- Doctor Dashboard: Allows authenticated practitioners to request access and view the patient's records upon approval.

The main key features of this website is it can support seamless upload and fetch of dental records using IPFS, handles Patient-side control of access permissions and also provides Real-time synchronization with blockchain-based smart contracts.

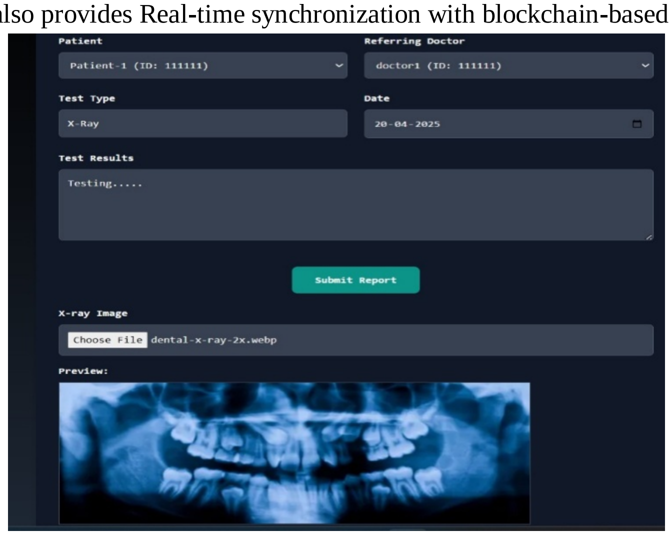

Fig: Interface to upload the patient's data.

3) ML Module Integration (Code Demonstration):Although not used for diagnosis in this system, the machine learning module for Dental Code generation was implemented in Python to process X-rays and extract unique features. The model outputs structured data based on inter-crown distances and alignment angles.

This module was successfully tested on real patient X-rays, proving that it can support future enhancements such as patient matching or automated dental records classification.

```
# Evaluate Model
correct_matches = 0
total_images = len(image_paths)

for query_path in image_paths:
    query_name = os.path.basename(query_path).split('.')[0]
    query_thresh = preprocess_image(query_path)
    query_dental_works = extract_dental_works(query_thresh)
    query_code = generate_dental_code(query_dental_works)

    predicted_name = match_dental_code(query_code, database_codes)

    if predicted_name == query_name:
        correct_matches += 1

accuracy = (correct_matches / total_images) * 100 if total_images > 0 else 0
print(f"Matching Accuracy: {accuracy:.2f}%")

Matching Accuracy: 96.88%
```

Fig: Model Evaluation

4) Performance Summary: The system performed efficiently under local testing conditions, validating its technical feasibility, usability, and security objectives.

VII. CONCLUSION

The system addresses the critical challenges associated with the secure storage, access control, and traceability of electronic dental records in a distributed environment. By integrating decentralized ledger technology with off-chain storage solutions, the architecture ensures data immutability, integrity, and confidentiality while supporting scalability and performance. This design facilitates a patient-centric model of healthcare data management, enabling users to retain ownership and control over their personal health information. A significant enhancement in this architecture is the integration of machine learning for automated analysis of dental radiographs. This enables the extraction of unique dental features and the generation of identifiable dental codes, which are then used for accurate patient identification and verification.

The combination of blockchain's immutability with ML-driven biometric analysis strengthens the reliability and scalability of dental healthcare systems. This approach not only secures sensitive medical data but also enhances the speed and accuracy of patient identification, supporting modern, data-driven clinical practices. Furthermore, the system supports auditability, ensuring that all access and data-related activities are permanently recorded and verifiable.

In conclusion, the system combines blockchain security with machine learning-driven dental code analysis to provide a reliable and intelligent solution for securely storing dental records and accurately identifying patients, ultimately enhancing data privacy, clinical efficiency in digital dental healthcare.

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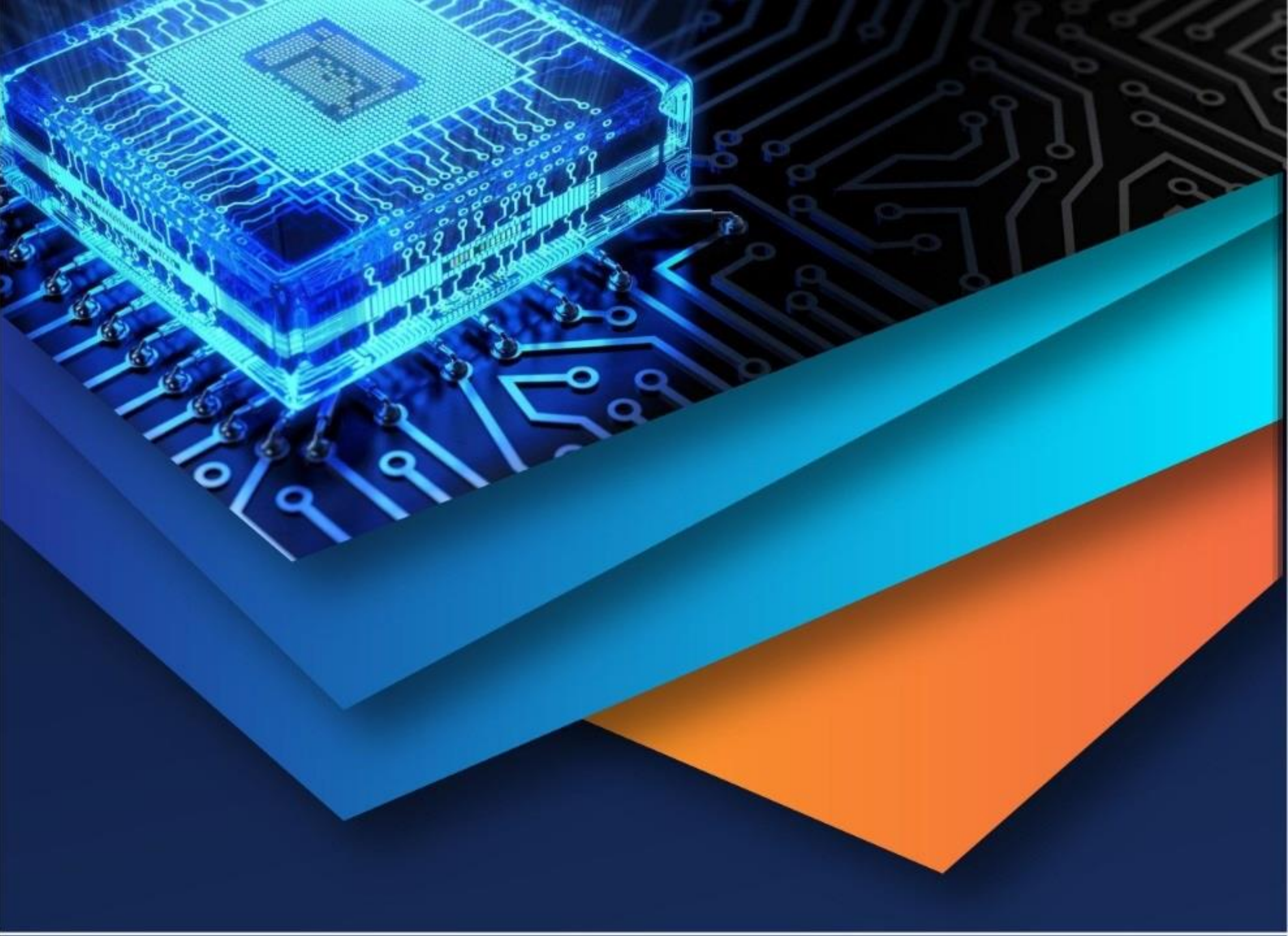

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