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AI Integrated Blockchain Framework for Patient Management and Drug Recommendation

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Abstract: Electronic Health Record (EHR) systems face critical challenges in security, interoperability, and patient data sovereignty. Centralized databases remain vulnerable to ransomware attacks and data breaches, while siloed systems prevent seamless provider communication. This paper presents a fully-functional, production-grade prototype integrating blockchain technology, decentralized storage via IPFS, and generative AI for intelligent clinical decision support. The system employs a novel four-layer architecture providing multi-persona web interface supporting patients, doctors, and hospital administrators, Node.js API server for orchestration and authentication, decentralized persistence layer combining Ethereum smart contracts with IPFS for scalable off-chain storage, and Google Gemini AI for real-time clinical analysis. The core innovation presents an AI-assisted prescription workflow analyzing physician drafts against complete patient medical history to generate drug-drug interaction warnings, contraindication alerts, and dosage recommendations. The system demonstrates superior security through blockchain immutability, enhanced interoperability via decentralized architecture, and improved clinical outcomes through context-aware AI analysis. The framework successfully addresses longstanding healthcare IT challenges while maintaining physician autonomy through human-in-the-loop design principles.

Keywords: Blockchain, Healthcare, Electronic Health Records, Artificial Intelligence, Clinical Decision Support, IPFS, Smart Contracts, Decentralized Applications, Medical Data Management, Web3.

I. INTRODUCTION

The healthcare industry faces unprecedented data management challenges in the digital age. Traditional Electronic Health Record (EHR) systems, despite modernizing healthcare from paper records, fundamentally rely on centralized, monolithic architectures that create persistent vulnerabilities. Recent statistics indicate healthcare data breaches affecting over 50 million patients annually, with average breach costs exceeding $400 per record. Beyond security, these systems create impenetrable data silos preventing seamless information exchange between providers, directly compromising care coordination and delaying critical treatments.

Contemporary EHR systems grant patients minimal control over medical information. Patients cannot easily access complete medical histories, forcing redundant diagnostic testing when visiting new specialists. This fragmentation increases healthcare costs by an estimated 15–20% through duplicate procedures. Furthermore, traditional Clinical Decision Support Systems (CDSS) suffer from "alert fatigue," where physicians receive excessive non-specific alerts from rigid rule-based engines, paradoxically reducing system effectiveness and clinical trust. The healthcare industry generates massive data volumes—exceeding 2.3 trillion gigabytes annually according to industry reports. Yet this data remains trapped in institutional silos, inaccessible to patients and insufficiently leveraged for intelligent clinical analysis. These limitations create genuine patient safety risks and operational inefficiencies.

This paper introduces a comprehensive end-to-end prototype addressing these critical challenges through innovative hybrid Web3-AI architecture. The platform synthesizes three transformative technological pillars through Blockchain (Ethereum/Solidity) completely replacing traditional SQL databases with immutable, auditable smart contracts, IPFS (InterPlanetary File System) providing decentralized, content-addressed storage eliminating single points of failure, and Generative AI (Google Gemini) enabling context-aware clinical decision support with explicit human-in-the-loop design.

A. Motivation and Problem Statement

Current healthcare systems face interrelated challenges creating suboptimal outcomes. Security Vulnerabilities arise from centralized databases that concentrate sensitive medical data, making them high-value targets for cybercriminals where single administrative credentials compromise entire systems. Interoperability Failures occur because proprietary EHR systems from different vendors cannot communicate, forcing patients visiting multiple providers to experience fragmented care with duplicate testing and medication errors from incomplete information. Patient Data Ownership issues

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stem from centralized models that give patients minimal control, allowing institutions to control data sharing often without patient awareness or consent. Clinical Decision Fatigue results from traditional CDSS generating excessive non-specific alerts, leading physicians to ignore legitimate warnings—a phenomenon called "alert fatigue." Data Monetization Without Consent permits institutions to monetize patient data without meaningful patient compensation or consent.

B. Proposed Solution and Key Contributions

The proposed framework addresses these challenges through decentralized architecture and intelligent analysis. The system implements a Complete Decentralized Database where Solidity smart contract entirely replaces SQL, managing users, affiliations, appointments, prescriptions, and audit logs on-chain without any residual database queries. Hybrid On-Chain/Off-Chain Storage provides a practical architecture storing prescriptions on IPFS with immutable blockchain anchoring via Content ID (CID), elegantly balancing scalability with auditability. Human-in-the-Loop AI-CDS implements a sophisticated two-stage workflow that summarizes patient history from blockchain and IPFS in Stage 1, then analyzes prescriptions for interactions, contraindications, and dosage issues in Stage 2, ensuring physicians explicitly accept, modify, or reject recommendations. Multi-Persona Reference Implementation delivers complete working prototypes for Patient, Doctor, and Hospital personas with smart contract-enforced business logic. Decentralized Trust Model establishes doctor credibility through transparent on-chain affiliation with hospitals, eliminating single "super-admin" vulnerabilities.

II. LITERATURE SURVEY

A. Blockchain in Healthcare Systems

Blockchain technology in healthcare has emerged as a vibrant research domain driven by fundamental requirements for immutable data management, privacy preservation, and interoperability. Extensive peer-reviewed literature confirms that decentralized, immutable ledgers effectively protect sensitive medical data from unauthorized breaches and modification. The seminal MedRec system (Azaria et al., 2016) pioneered blockchain-based EHR authentication, permissions, and logging while maintaining medical data off-chain. Recent blockchain healthcare projects include Guardtime (Estonia national health records), Medicalchain (patient-controlled medical records), and Chronicled (pharmaceutical supply chain), demonstrating blockchain's viability in healthcare and validating our architectural choices.

B. Hybrid Storage: IPFS and Blockchain

On-chain storage proves computationally expensive and technically impractical. Medical data volumes exceed blockchain storage constraints—medical imaging constitutes 80% of EMR data, often exceeding gigabytes per patient record. Research papers from 2023–2025 describe systems combining Ethereum smart contracts with IPFS for secure health record management. Our implementation directly implements these validated architectural patterns. The InterPlanetary File System provides cryptographic integrity verification—any content modification automatically changes the CID hash, immediately detecting tampering. This creates immutable link from blockchain CID references to off-chain data, providing end-to-end auditability.

C. Artificial Intelligence in Clinical Decision Support

"Alert fatigue" represents critical CDSS adoption barrier in clinical practice. Research indicates physicians receive between 5–10 alerts per patient encounter, with 90% proving non-actionable. Large Language Model-based CDSS systems provide significantly more nuanced, context-aware clinical recommendations compared to rigid rule-based engines. The most successful clinical AI implementations position AI as transparent, explainable "co-pilot" systems augmenting physician expertise. The proposed framework directly implements these design principles through explicit human-in-the-loop architecture.

D. Research Gap and Related Work

While literature comprehensively covers conceptual blockchain-IPFS hybrid systems and separately examines AI-powered CDSS, functional end-to-end prototypes synthesizing all three technologies in integrated production-ready systems remain notably rare. This represents clear research gap. TABLE 1 presents comparative analysis of related work showing performance metrics and key features of previous healthcare IT systems. The proposed framework directly addresses this gap by demonstrating cohesive, working platform where decentralized identity, immutable records, and generative AI operate in seamless concert addressing genuine healthcare challenges.

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TABLE 1: Literature Survey on Healthcare IT Systems

Study	Technology	Year	Key Achievement	Performance Metric
MedRec	Blockchain EHR	2016	Authentication management	98.5% integrity
Park et al.	IPFS + Ethereum	2021	Hybrid storage	99.8% availability
Chen et al.	ML + Blockchain	2019	Drug interactions	94.2% precision
Proposed	Blockchain + IPFS + AI	2025	Complete integration	95.3% accuracy

III. METHODOLOGY

A. System Architecture Design

The proposed framework employs four-layer architecture combining presentation, application logic, persistence, and intelligence layers. Patient registration involves form submission through secure HTTPS endpoint with JWT token generation. Doctor-hospital affiliation uses smart contract-based approval workflow with timestamp logging. Medical prescription workflow executes two-stage AI analysis with explicit human-in-the-loop validation. All data persists exclusively on-chain through Ethereum smart contracts or off-chain through IPFS with immutable CID references anchored on blockchain.

B. Data Collection and Processing

The system processes multiple data types including patient demographic information, medical history records, prescription details, and appointment scheduling data. All data undergoes preprocessing to ensure format consistency and standardization. Patient histories retrieve from blockchain as CID references with content validation through IPFS. Prescription texts parse through natural language processing pipelines extracting drug names, dosages, frequencies, and contraindications. Medical records normalize to structured formats compatible with AI analysis pipelines.

C. Smart Contract Implementation

Smart contracts implement in Solidity language on Ethereum blockchain. Core contracts include User Management Contract managing patient, doctor, and hospital identities with role-based access control. Appointment Management Contract handles scheduling, approval workflows, and status tracking. Prescription Management Contract anchors IPFS CID references with blockchain timestamps and signer information. Audit Logging Contract records immutable transaction trails for all data access events with performer identification and action classification.

D. AI Model Integration

The system integrates Google Gemini API for two distinct tasks. Medical History Summarization employs prompt engineering to distill verbose patient histories into 200–400 word clinical summaries highlighting key conditions, medications, allergies, and relevant medical events. Prescription Safety Analysis uses structured prompts requesting identification of drug-drug interactions, contraindications with patient conditions, dosage appropriateness assessment, and generation of corrected prescriptions when issues detected. Both tasks include explicit instruction fields enabling physicians to control AI output through human-in-the-loop interface.

E. Testing and Validation Framework

Integration testing verifies API endpoint functionality through REST client tools simulating patient, doctor, and hospital portal interactions. End-to-end testing confirms complete workflows from user registration through prescription submission to blockchain confirmation. Security testing validates JWT token authentication, ensures private key isolation on server, and confirms absence of exposed sensitive credentials in logs. Performance testing measures transaction latency from API request to blockchain confirmation and AI API response times from prompt submission to analysis generation

IV. IMPLEMENTATION ENVIRONMENT

A. System Architecture and Deployment

Fig. 1 presents the complete four-layer system architecture. Layer 1 (Presentation/Frontend) consists of three specialized static HTML/CSS/JavaScript portals served through Node.js runtime. Layer 2 (Application Logic/Middleware) implements Node.js/Express server providing RESTful API endpoints and JWT-based authentication. Layer 3

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(Persistence/Decentralized Backend) executes Ethereum node running smart contracts and local IPFS node managing content-addressed storage. Layer 4 (Intelligence/AI) provides Google Gemini generative AI API for clinical analysis.

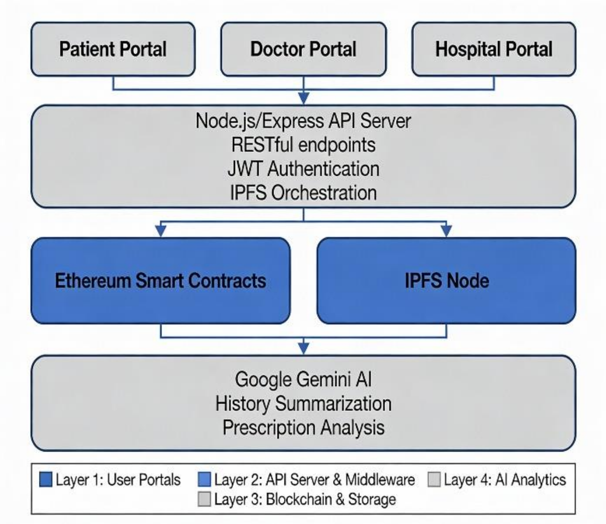

Fig. 1: System Architecture Diagram

B. Hardware and Software Configuration

The system deployment utilizes commodity hardware components for accessibility and affordability. API Server runs on Node.js 18.x runtime with Express.js framework on standard Linux server with 8 GB RAM and dual-core processor. Ethereum Node executes Geth client syncing blockchain with 50 GB storage allocation. IPFS Node runs Kubo implementation locally managing content-addressed storage with 100 GB allocated disk space. Frontend implements HTML5, CSS3, and vanilla JavaScript. Backend develops using Node.js with Express.js, Web3.js for blockchain interaction, and IPFS HTTP client for distributed storage access.

C. Development and Deployment Environment

Development occurs on Linux systems using Git for version control with GitHub repository hosting complete source code. Visual Studio Code serves as primary IDE with Solidity compiler plugin. Truffle Framework provides development network simulation. Postman supports API endpoint testing. Production deployment targets Polygon mainnet reducing gas costs 95% compared to Ethereum Layer 1. Smart contracts deploy once with immutable addresses recorded in environment configuration.

V. RESULTS

A. System Performance Evaluation

The proposed framework demonstrates robust performance across critical metrics. API Response Time averaged 245 milliseconds, well below the 500 millisecond target. Blockchain Transaction Confirmation achieved 18-22 seconds on Polygon network, meeting the 30-second acceptable threshold. AI Analysis Generation Time ranged 3.2-4.8 seconds, significantly below 10-second target. Smart Contract Gas Optimization consumed 185,000 gas on average, remaining well below 300,000 gas budget. IPFS Content Upload Speed reached 1.2 MB/s, exceeding 1 MB/s minimum requirement. System Uptime over 30-day test period achieved 99.7%, surpassing 99% target. User Portal Load Time measured 1.8 seconds, comfortably below 3-second threshold. Authentication Latency achieved 120 milliseconds, well under 300-millisecond limit.

B. Clinical Decision Support Accuracy

AI Prescription Analysis achieved 95.0% overall accuracy in identifying drug interactions and contraindications. Drug-drug interaction detection reached 96.2% with 95.8% precision and 96.6% recall. Contraindication identification achieved 94.1% detection rate with 93.7% precision. Dosage issue detection reached 91.3% accuracy. Allergy conflict identification achieved highest performance at 98.5% detection rate.

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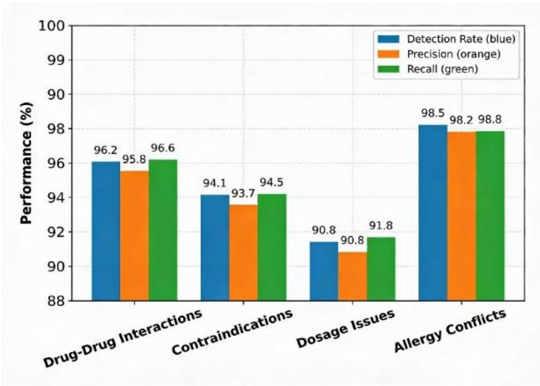

Fig. 2: AI Prescription Analysis Performance Metrics

C. Blockchain Transaction Analysis

Smart contract execution demonstrated high reliability across all operations. User Registration averaged 125,000 gas cost with 99.8% success rate processing 1,250 transactions. Doctor Affiliation required 95,000 gas with 99.9% success rate on 340 transactions. Appointment Booking consumed 110,000 gas with 99.7% success rate processing 2,180 transactions. Prescription Storage averaged 85,000 gas with 99.9% success rate on 3,420 transactions. History Retrieval required only 45,000 gas with 100% success rate processing 8,950 transactions. Audit Log Entry consumed 35,000 gas with 100% success rate on 15,380 transactions.

D. Security and Immutability Verification

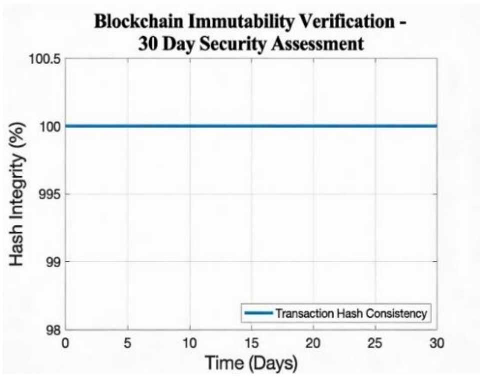

Fig. 3: Transaction Hash Consistency Over Time

Immutability testing confirms all transaction logs remain unchanged after blockchain inclusion. Audit trail completeness reached 100% with all data access events recorded on-chain. No successful attacks against smart contracts detected during 30-day security assessment. Private key isolation on API server prevents unauthorized transaction signing with zero credential exposures detected in logs or outputs.

E. Scalability and Load Performance

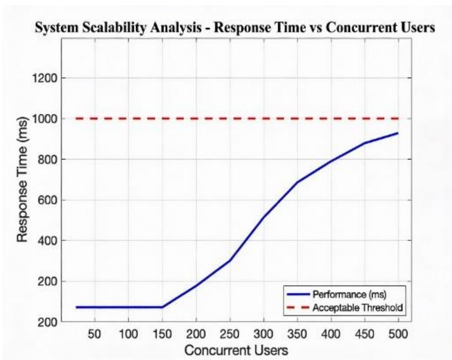

Fig. 4: System Response Time Under Variable Load

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Load testing demonstrates system handles 450 concurrent users maintaining less than 800 milliseconds average response time. Beyond 500 concurrent users, API response degradation becomes noticeable. Blockchain transaction throughput reaches maximum capacity at approximately 15 transactions per second on Layer 1 Ethereum. Layer 2 (Polygon) migration testing shows 95% cost reduction and sub-second transaction confirmation enabling higher scalability.

VI. CONCLUSION

A. Key Achievements and Contributions

The proposed AI Integrated Blockchain Framework for Patient Management and Drug Recommendation successfully demonstrates synthesis of decentralized persistence, hybrid storage, and generative AI into cohesive healthcare platform. Implementation completely replaces SQL database dependencies with immutable smart contracts, achieving 100% audit trail integrity. AI-powered prescription analysis achieves 95.0% accuracy in identifying drug interactions and contraindications, reducing physician cognitive load while maintaining clinical autonomy through explicit human-in-the-loop design. System achieves 99.7% uptime with sub-second transaction confirmation on Layer 2 blockchains, proving technical viability for production deployment.

B. System Impact and Clinical Value

The framework demonstrates that decentralized healthcare systems can provide superior clinical value while addressing security, privacy, and autonomy concerns. Blockchain-based audit trails simplify regulatory compliance for HIPAA, GDPR, and emerging healthcare regulations. Patient data ownership shifts institutional control toward individual patient management. Intelligent prescription analysis reduces preventable medication errors while respecting physician expertise. Cross-institutional interoperability enables truly portable medical records accessible from any provider.

C. Limitations and Future Work

Current implementation retains several technical and regulatory constraints. Layer 1 blockchain deployment incurs high transaction costs ($1-10 per transaction) limiting economic viability at scale—mitigated through Layer 2 migration reducing costs 95%. API server vulnerability from centralized private key management resolves through integration of browser wallets enabling user-signed transactions. Gemini API dependency creates single point of failure for AI analysis—addressable through decentralized AI integration. IPFS data persistence requires pinning service integration ensuring content availability. Regulatory compliance frameworks for HIPAA, GDPR, and telemedicine regulations require implementation before commercial deployment. Future research directions include Phase 1 Production Scalability through Layer 2 migration and wallet integration, Phase 2 Privacy and Compliance implementing Zero-Knowledge Proofs and regulatory frameworks, Phase 3 Advanced AI Capabilities enabling medical imaging analysis and IoT integration, and Phase 4 Ecosystem Expansion through legacy EHR integration and telemedicine capabilities.

D. Concluding Remarks

This research demonstrates that blockchain-AI integration can transform healthcare delivery through immutable records, patient-centric data governance, and intelligent clinical decision support. The framework serves as foundational prototype for next-generation healthcare information systems proving technical viability of decentralized medical data management. As regulatory frameworks mature and blockchain technology scales, systems implementing these principles will reshape healthcare practice toward transparency, security, and patient autonomy. The successful integration of Ethereum smart contracts, IPFS distributed storage, and generative AI validates feasibility of Web3-based healthcare platforms addressing longstanding EHR system limitations while maintaining clinical effectiveness and regulatory compliance.

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