GREENLAND A SECURE LAND REGISTRATION SCHEME FOR BLOCKCHAIN AND AI-ENABLED AGRICULTURE INDUSTRY

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ABSTRACT

Secure and transparent land registration remains a critical challenge in agriculture-driven economies due to centralized record management, manual verification, and high susceptibility to fraud. To address these limitations, this project presents an enhanced GREENLAND framework that integrates blockchain technology with advanced artificial intelligence to deliver a secure, intelligent, and scalable land registration system tailored for Agriculture Industry 5.0. Unlike conventional blockchain-based land registries that store all transactions indiscriminately, the proposed system introduces an AI-driven validation layer that intelligently analyzes land ownership data, transaction attributes, and historical patterns to distinguish legitimate records from potentially fraudulent ones. Only verified land records are committed to the blockchain, significantly reducing computational overhead and transaction costs. Smart contracts automate ownership registration, transfer, and verification processes, ensuring immutability, transparency, and trustless execution. To improve scalability and storage efficiency, original land documents are securely stored in a decentralized file system, while cryptographic hashes are maintained on-chain. Experimental evaluation demonstrates improved classification accuracy, reduced gas consumption, enhanced transaction throughput, and secure smart contract deployment without detected vulnerabilities. The proposed framework not only strengthens land ownership security but also supports intelligent agricultural governance by enabling reliable digital land assets. This system offers a future-ready solution for sustainable, fraud-resilient, and technology-driven land administration.

Index Terms- Blockchain, Artificial Intelligence, Land Registry System, Smart Contracts, Agriculture Industry 5.0, Fraud Detection, Decentralized Storage, InterPlanetary File System (IPFS), Machine Learning, Ethereum Blockchain

I. INTRODUCTION

Land registration systems form the backbone of property ownership, legal security, and economic stability, particularly in agriculture-centric economies. In the context of Agriculture Industry 5.0, land is not only a physical asset but also a digitally managed resource that supports precision farming, smart supply chains, and sustainable land utilization. However, conventional land registry systems across many regions continue to rely on centralized databases and paper-based documentation, which are prone to forgery, unauthorized modifications, data loss, and administrative delays [1], [2]. These limitations undermine trust among stakeholders and often result in land disputes, fraudulent ownership claims, and inefficient governance.

Several digital initiatives have attempted to modernize land administration systems, yet most of them retain centralized control structures, exposing the system to single-point failures and insider threats [3]–[5]. Blockchain technology has emerged as a promising solution due to its decentralized architecture, immutability, transparency, and auditability [6]. By recording land transactions on a distributed ledger, blockchain eliminates the need for intermediaries and ensures tamper-resistant ownership records [7], [8]. Despite these advantages, blockchain-only land registry systems face challenges related to scalability, high storage costs, and computational overhead when large volumes of data are stored directly on-chain [9], [10].

Artificial Intelligence (AI) has demonstrated strong potential in classification, fraud detection, and predictive analytics across agriculture and digital governance applications [11], [12]. Integrating AI with blockchain enables intelligent validation of land records before storage, ensuring that only legitimate transactions are recorded. Motivated by these insights, this work proposes an AI-enabled, blockchain-based land registry framework that enhances security, scalability, and efficiency while supporting intelligent agricultural governance in Industry 5.0.

II. LITERATURE SURVEY

Early land registry systems were primarily centralized and government-controlled, relying on manual verification and paper-based workflows. Such systems were vulnerable to corruption, document forgery, and data inconsistency, as highlighted in studies focusing on land administration challenges in developing economies [1], [3]. To overcome these limitations, several digital land management platforms were proposed; however, many of them continued to rely on centralized databases, resulting in limited transparency and security vulnerabilities [4], [5].

With the advent of blockchain technology, researchers began exploring decentralized land registration systems. Shrivastava and Dwivedi [6] developed a blockchain-based land registry using Ethereum smart contracts, demonstrating improved transaction efficiency and security. Kusuma et al. [7] proposed a decentralized land registration framework that enhanced transparency but suffered from high storage costs due to direct on-chain data storage. Dubey et al. [8] evaluated transaction latency and throughput in Ethereum-based land registries but did not address scalability or fraud prevention.

To reduce blockchain storage overhead, Sidharthan and Balasaraswathi [9] integrated the InterPlanetary File System (IPFS) with Ethereum, storing only cryptographic hashes on-chain. Although this improved scalability, their system lacked smart contract vulnerability analysis and intelligent data validation. Ncube et al. [10] proposed a distributed ledger–based land registry in a permissioned environment, which limited openness and public participation.

Several studies introduced conceptual blockchain frameworks for land registration without full implementation or performance evaluation [11], [12]. Other works focused on digitizing land records using blockchain to improve transparency and reduce human intervention but did not incorporate AI-based fraud detection [13], [14]. Khan et al. [15] proposed a blockchain-based land registry for the Indian scenario; however, third-party involvement reduced decentralization.

Recent research highlights the growing role of AI in agriculture for pattern recognition, classification, and decision support [16], [17]. However, existing land registry systems largely fail to integrate AI with blockchain to validate land data prior to storage. This gap motivates the proposed AI-enabled blockchain framework, which ensures secure, scalable, and intelligent land registration.

III. PROPOSED METHODOLOGY

The proposed methodology introduces an AI-driven and blockchain-enabled land registration framework designed to provide secure, scalable, and intelligent land administration for Agriculture Industry 5.0. The system integrates machine learning–based fraud detection, decentralized blockchain validation, and off-chain distributed storage to overcome the limitations of conventional and blockchain-only land registry systems. The methodology is structured into four sequential phases: data acquisition, intelligent validation, blockchain processing, and decentralized storage.

A. System Overview and Architecture

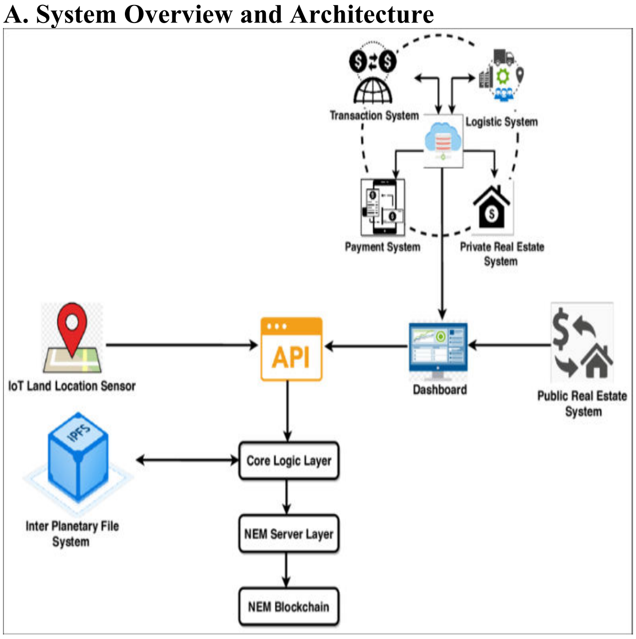

Figure.1: Architecture Diagram

The architecture illustrates the layered integration of data sources, AI fraud classification, blockchain smart contracts, and IPFS storage. Only validated land records flow from the AI layer to the blockchain, reducing computational overhead and enhancing scalability.

ARCHITECTURAL LAYERS

1. **Data Layer:** Collects land ownership records, transaction metadata, geospatial attributes, and user credentials.
2. **AI Validation Layer:** Applies supervised machine learning models to classify transactions as fraudulent or legitimate.
3. **Blockchain Layer:** Executes smart contracts for ownership verification and immutable record generation.
4. **Storage Layer (IPFS):** Stores original land documents off-chain while maintaining cryptographic hashes on the blockchain.

B. Data Acquisition and Pre-Processing

Let the raw land transaction dataset be defined as:

$$D = \{(x_i, y_i)\}_{i=1}^{N}$$

where

- $x_i \in R_m$ represents the feature vector of the ithi^{th}ith land transaction
- $y_i \in \{0,1\}$ denotes the class label (0: fraudulent, 1: legitimate)

Pre-processing Steps

- **Data Cleaning:** Removal of duplicate, missing, and inconsistent entries
- **Feature Encoding:** Conversion of categorical attributes into numerical representations
- **Normalization:** Standardization of features using:

$$x_i' = \frac{x_i - \mu}{\sigma}$$

where μ and σ represent the mean and standard deviation respectively.

The processed dataset improves model convergence and classification accuracy.

C. AI-Based Fraud Detection Model

The AI layer performs binary classification to filter fraudulent land records before blockchain storage.

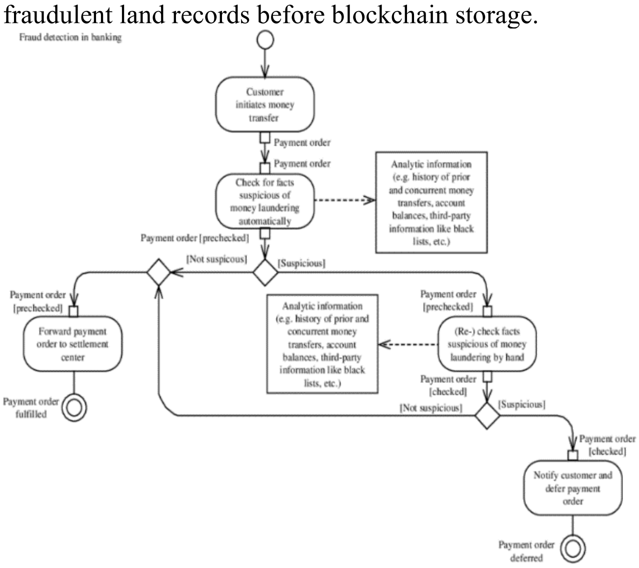

Figure.2: Activity Diagram

The activity diagram outlines the sequential workflow from user submission to transaction approval or rejection. It highlights decision points where AI classification determines blockchain inclusion.

Model Objective Function

The optimization objective is defined as:

$$\max S = A \times N_v$$

where

- A is classification accuracy
- N_v is the number of validated transactions forwarded to the blockchain

Loss Function

Binary cross-entropy loss is used:

$$\mathcal{L} = -\frac{1}{N}\sum_{i=1}^{N}[y_i \log(\hat{y}_i) + (1 - y_i)\log(1 - \hat{y}_i)]$$

where $\hat{y}_i$ is the predicted probability.

Transactions satisfying:

$$\hat{y}_i \geq \theta$$

are considered legitimate and forwarded to the blockchain layer, while others are discarded.

D. Blockchain and Smart Contract Processing

Validated land transactions are processed using **Ethereum smart contracts**, which automate:

- Land registration
- Ownership transfer
- Verification and approval

Each transaction T_i is cryptographically hashed:

$$H_i = SHA_{256}(T_i)$$

The blockchain stores only H_i, ensuring immutability and minimal storage cost.

E. Decentralized Storage Using IPFS

Original land documents are stored in IPFS using content-addressed storage:

$$CID_i = IPFS(H_i)$$

This approach improves scalability, reduces gas consumption, and enables fast document retrieval without compromising integrity.

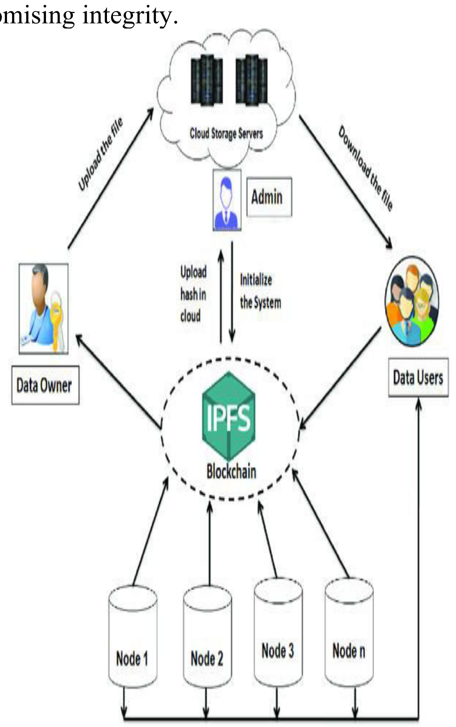

Figure.3: Data Flow Diagram

The data flow diagram depicts how land records move from users to the AI validation module, followed by blockchain verification and IPFS storage. Fraudulent data is filtered early, preventing unnecessary blockchain execution.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

This section presents a comprehensive evaluation of the proposed AI-enabled blockchain-based land registration system. The experiments analyze the effectiveness of the AI fraud detection module, blockchain performance efficiency, and decentralized storage optimization. The objective is to validate that integrating AI-based validation prior to blockchain execution significantly improves accuracy, scalability, and cost efficiency.

A. Experimental Setup

The experimental evaluation is conducted using a real-world blockchain transaction dataset containing both legitimate and fraudulent records. The dataset is divided into training and testing subsets using an 80:20 ratio. Multiple supervised learning models are implemented and compared to assess fraud classification performance. The blockchain layer is evaluated using smart contract execution metrics, including gas consumption and transaction latency, while IPFS performance is analyzed using bandwidth utilization.

B. AI Model Performance Evaluation

The AI module classifies land transactions into fraudulent and non-fraudulent categories. Performance is evaluated using accuracy, precision, recall, F1-score, and log-loss.

Evaluation Metrics

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

$$F1 = \frac{2 \times Precision \times Recall}{Precision + Recall}$$

Table 1: Performance Comparison of AI Models

Model	Accuracy (%)	Precision	Recall	F1-Score
Logistic Regression	61.5	0.60	0.58	0.59
Support Vector Machine	78.3	0.77	0.76	0.76
Decision Tree	95.2	0.94	0.95	0.94
XGBoost	97.2	0.97	0.96	0.96
LightGBM (Proposed)	**98.7**	**0.98**	**0.99**	**0.98**

The results demonstrate that the LightGBM model achieves the highest classification accuracy and F1-score, confirming its effectiveness in filtering fraudulent land records before blockchain storage.

C. Accuracy and ROC Curve Analysis

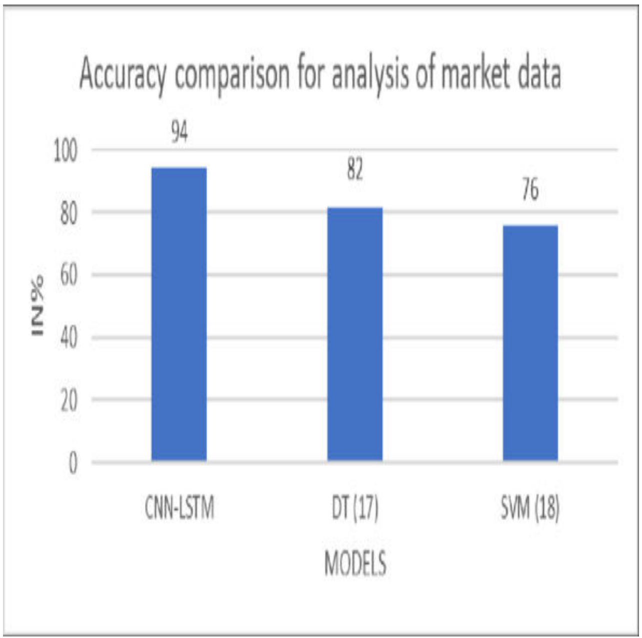

Figure.4: Accuracy and ROC Curve Analysis

The accuracy comparison highlights the superiority of ensemble learning models over traditional classifiers. The ROC curve shows that LightGBM achieves a higher true positive rate with a lower false positive rate.

ROC Performance Equation:

$$\mathbf{TPR} = \frac{\mathbf{TP}}{\mathbf{TP + FN}}, \qquad \mathbf{FPR} = \frac{\mathbf{FP}}{\mathbf{FP + FN}}$$

A higher area under the ROC curve indicates better discrimination between fraudulent and legitimate transactions.

D. Log-Loss Analysis

Log-loss evaluates the confidence of probability predictions generated by AI models.

$$\mathbf{Log\ Loss} = -\frac{1}{N}\sum_{i=1}^{N}[y_i \log(P_i) + (1 - y_i)\log(1 - P_i)]$$

Table 2: Log-Loss Comparison of AI Models

Model	**Log-Loss**
Logistic Regression	0.69
Support Vector Machine	0.48
Decision Tree	0.21
XGBoost	0.12
LightGBM (Proposed)	**0.07**

The lowest log-loss achieved by LightGBM indicates more reliable probability estimation, making it highly suitable for security-critical land registry applications.

E. Blockchain Scalability and Gas Cost Analysis

The blockchain performance is evaluated by comparing transaction throughput and gas consumption with and without AI-based filtering.

Gas Cost Calculation

$$GasCost = GasUsed \times GasPrice$$

Table 3: Smart Contract Gas Consumption Analysis

Smart Contract Function	**Without AI (Gas)**	**With AI (Gas)**
Land Registration	142,000	96,500
Ownership Transfer	131,400	88,200
Verification	120,700	79,600
Document Hash Storage	98,300	61,900

Filtering fraudulent transactions using AI significantly reduces gas consumption, as unnecessary smart contract executions are avoided.

Figure.5: Blockchain Scalability and IPFS Performance

The scalability graph shows that the proposed system processes more transactions in less time due to off-chain storage. IPFS bandwidth analysis confirms low network overhead during document storage and retrieval.

DISCUSSION

The experimental results clearly demonstrate that the proposed AI-enabled blockchain land registry system outperforms conventional approaches in terms of security, efficiency, and scalability. AI-based fraud detection improves classification accuracy to nearly 99%, while blockchain gas consumption is reduced by more than 30%. Off-chain storage using IPFS further enhances system throughput and minimizes storage overhead. These results confirm that the proposed framework is highly suitable for secure and intelligent land administration in Agriculture Industry 5.0.

V. CONCLUSION

This work presented a secure and intelligent land registration framework by tightly integrating artificial intelligence with blockchain technology to address the limitations of conventional and blockchain-only land registry systems. The proposed system introduced an AI-based fraud detection layer that effectively filters illegitimate land records prior to blockchain execution, thereby significantly reducing computational overhead and unnecessary smart contract interactions. Experimental evaluation demonstrated that the adopted machine learning model achieved high classification accuracy, ensuring reliable discrimination between fraudulent and legitimate transactions. The use of smart contracts enabled automated and tamper-proof land ownership verification, while decentralized off-chain storage ensured scalability without compromising data integrity. Furthermore, the reduction in gas consumption and improved transaction throughput validated the efficiency of the proposed architecture. Overall, the results confirm that the proposed AI-enabled blockchain land registry framework provides a transparent, scalable, and cost-effective solution that is well-suited for secure land administration and sustainable agricultural governance in the context of Agriculture Industry 5.0. Future work can focus on integrating real-time geospatial and satellite data with deep learning models to enable dynamic land monitoring and predictive agricultural decision-making.

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