MSW MANAGEMENT -Multidisciplinary, Scientific Work and Management Journal
ISSN: 1053-7899
Vol. 36 Issue 1s, 2026, Pages: 3651-3655

FarmLedger: A Blockchain and AI-Based Secure Land Registration Framework for Smart Agriculture

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Abstract:
Ownership of land is key factor in promoting agricultural development and economic growth; however, the existing system of registering land is susceptible to corruption, data corruption and claims to ownership of land. In order to address these obstacles, blockchain technology is used to provide the land registration with an immutable and tamper-proof registry to guarantee the integrity and transparency of the data. The following paper suggests a secure and transparent land registration system, FarmLedger, for the agricultural industry, which integrates blockchain and artificial intelligence technologies. The identification and filtering of the fraudulent land registration data are done through artificial intelligence algorithms, including logistic regression, support vectors machines, and random forest classifiers and then written to the blockchain.. This verification step prevents fraudulent data from being written to the blockchain network and avoids unnecessary computational overhead. Smart contracts are used to automate the verification of land registration data. Verified and non-fraudulent land data is safely stored using IPFS, while the corresponding hash values are written to the blockchain for secure data access and authenticity. Moreover, an extensive performance analysis is carried out to assess the efficacy and trustworthiness of the proposed system. The FarmLedger system greatly enhances trust among participants and eliminates land-related disputes with a fraud-proof land registration system.
Keywords: Blockchain, FarmLedger, Land Registration, Artificial Intelligence, IPFS, Fraud Detection, Smart Contracts

Introduction:

The fast-paced development of agriculture and Industry 5.0 has greatly impacted the use of land through the application of advanced technologies such as precision agriculture, smart crop management, and smart industry. These technologies improve efficiency, optimize resource use, increase productivity, and minimize environmental effects, opening doors to sustainable development. In this regard, functional land registry systems have become necessary to facilitate modern agriculture and industry. Governments around the world highlight the importance of secure land ownership verification and transfer of ownership to ensure transparency, avoid conflicts, and facilitate secure property transactions. However, the current land registry systems have major drawbacks. Conventional systems heavily depend on centralized government databases to store and control ownership information and land transfer [1], [2]. Although these systems are intended to ensure legitimacy and governance, they are prone to single-point failure, data tampering, corruption, and cyber-attacks. Various digital systems for land management have been suggested to overcome these issues, such as cadastral information systems and web-based land registry systems. Although these systems improve accessibility and efficiency, they are still prone to security risks due to the vulnerability of sensitive land information stored in centralized databases, thus undermining public trust.

Blockchain technology has recently been recognized as a viable option to address the limitations of centralized systems [3]. The nature of block-chain technology ensure transparency, traceability, and tamper-resistance. With blockchain technology, land ownership transactions can be recorded on a decentralized ledger [4], removing the need for intermediaries and improving stakeholder trust. Smart contracts also enable the automation. However, many blockchain systems are currently experiencing scalability problems, high computational requirements, and inadequate validation processes for authenticating the accuracy of land information prior to storage. In this regard, this research proposes an integrated land registry system that combines blockchain and AI technologies. AI classification techniques are used to authenticate land ownership and agricultural information, separating valid information from invalid or conflicting information. This process enables the automation of land information validation, reducing human involvement, speeding up transaction processing, and minimizing errors and costs. Only valid information is stored in decentralized file storage systems like IPFS, and the cryptographic hash of the information is stored on the blockchain, which greatly enhances scalability and network performance[5].In addition, the blockchain technology ensures data security, privacy, and integrity, which prevents unauthorized access and modification of the land records. The proposed system also employs smart contract vulnerability assessment tools to verify the validity of the smart contract prior to its deployment, The invalid data is filtered by AI before it is stored in the blockchain, which further enhances the performance of the system.

Literature Review:

This section reviews recent advanced methods that have been developed to improve land registry systems.. In recent years, blockchain-based solutions have gained attention as a promising way to enhance transparency, security, and operational efficiency [6], in land registration processes. For instance, Kusuma et al. introduced a decentralized blockchain framework integrated with smart contracts [7], aimed at reducing fraudulent activities while also lowering the time and financial costs associated with land registration procedures. However, their system is dependent on the Ethereum platform for storing the entire data, resulting in high costs of operation and slower data retrieval compared to distributed storage systems like IPFS. Moreover, the lack of AI capabilities restricts their system from filtering fraudulent transactions prior to blockchain storage.Shrivastava and Kumar Dwivedi proposed a secure and efficient blockchain-based land registry system [8], but their system does not incorporate IPFS and AI capabilities, potentially causing the storage of unnecessary fraudulent data. Similarly, Ncube et al. proposed a secure and reliable blockchain-based distributed ledger system [9], [10] enabled by smart contracts . However, their system is based on a permissioned system and lacks IPFS storage and AI capabilities.

Other research papers concentrated on reliability and digitization. Khalid et al. introduced a conceptual framework that is decentralized [11]. Suganthe et al. introduced blockchain technology for digitizing land records in India [12], but the presence of third-party agents causes security concerns and lacks AI support. Mishra et al. concentrated on combating corruption using blockchain transparency [13], but their paper lacks implementation details and intelligent fraud detection.

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Other research papers introduced Ethereum storage solutions, Hyperledger Fabric, and peer-to-peer solutions that enhance decentralization and resistance to tampering but are often expensive, permissioned, and lack AI support. Some papers only concentrate on storing documents and not the entire land registration process.Several researchers have also proposed blockchain frameworks for secure land registration where transaction records are stored in decentralized ledgers to prevent tampering and unauthorized modifications [14].
The existing literature emphasizes the use of blockchain technology but points out important shortcomings such as inefficient storage, lack of intelligent fraud detection, poor scalability, and the need for third-party agents. This clearly indicates the need for a reliable land registry system that combines blockchain technology and AI storage solutions to provide fully automated solution. In order to improve transparency and dependability, it is crucial to integrate secure storage, intelligent validation mechanisms, and decentralized infrastructures, according to recent survey studies that have examined various blockchain-based land registry systems [15].

INFERENCE FROM THE EXISTING SYSTEM

The existing solution combines blockchain technology and artificial intelligence to solve long-standing problems in agricultural land registration. Blockchain technology is used as an immutable ledger that securely stores land information, [16] making it transparent and traceable. To ensure that no false or tampered data is entered, AI models are used to analyze land information and categorize it as authentic or fake before it is entered into the system. This way, only authentic and trustworthy information is stored, making the system more computationally efficient and accurate.Smart contracts are also used to improve the system by automatically authenticating land information based on set rules, minimizing human interaction, and ensuring security. Authentic land information is also stored in the IPFS, while the hash value of the information is stored in the blockchain to ensure data integrity and easy access. The system also has a comprehensive performance analysis, which includes the accuracy of AI models, scalability of blockchain technology, and security of smart contracts[17]. These analyses work together to ensure the development of a trustworthy and transparent land registration system.The existing system is still dependent on conventional AI models like logistic regression and support vector machines, which may not be efficient in processing complex and large amounts of data. The system does not have real-time monitoring, which makes it slower in identifying fraud and responding to problems.

ROPOSED SYSTEM

The proposed framework improves the existing land registration system process by incorporating modern technologies that boost efficiency, accuracy, and usability in the agricultural and related sectors. By incorporating intelligent machine learning algorithms such as XGB and LGBM, the framework improves its capacity to identify and prevent fraudulent activities, even in the most complex data sets. The real-time surveillance system continuously tracks transactions and immediately notifies the concerned authorities in case of any suspicious activity, allowing for faster action.The adaptive smart contracts are capable of automatically adapting to changes in the regulatory framework while also improving the accuracy of data validation procedures. The incorporation of external land record databases and GIS systems further improves the accuracy and consistency of the land data. To facilitate the growth of large data sets, the system utilizes sharding methods, thereby ensuring improved scalability and performance.The decentralized digital identity system ensures the privacy of the concerned landowners while maintaining high levels of security. Additionally, the advanced threat and vulnerability analysis systems protect smart contracts from possible threats. The intelligent system also encourages responsible and sustainable land use practices. Finally, the user-friendly interface ensures a seamless user experience and easy access to land records. The proposed system provides improved security and fraud detection capabilities with the use of advanced AI models such as XGB and LGBM, along with real-time monitoring capabilities for faster action.

METHODOLOGY

Developed a secure and intelligent land registration system by combining artificial intelligence (AI), blockchain technology, and decentralized storage. The proposed system aims to avoid forgery of land records, minimize computational complexity, and improve transparency in agriculture and Industry 5.0-based land registration systems. The proposed approach is based on a three-layer structure, including the data layer, AI layer, and blockchain layer. In the data layer, the initial land transaction data is gathered. The gathered data is used as input for further verification and analysis. In the AI layer, the gathered data is preprocessed using various techniques such as data cleaning, missing value treatment, feature selection, and normalization [19]. The relevant features of the land transactions are identified and used to train supervised machine learning classifiers. Various classifiers, such as Logistic Regression, SVM, Random Forest, Extreme Gradient Boosting, and LGBM are compared to identify the best classifier. The training of the models in the machine learning is done through various iterations in order to optimize the parameters and reduce the classification errors. The models learn from the data provided in the training set during each iteration and update their internal parameters to achieve high accuracy in the predictions. The models continue the learning through various iterations until convergence is achieved or the number of iterations is complete, helping the system to effectively distinguish between the fraudulent and genuine land transactions. to differentiate between fraudulent and genuine land transactions. Smart contracts were developed and tested using the Remix Solidity IDE [20] .In this study, the models were trained for multiple iterations, where boosting algorithms such as XGBoost and LightGBM perform iterative gradient optimization to improve classification performance.

ARCHITECTURE

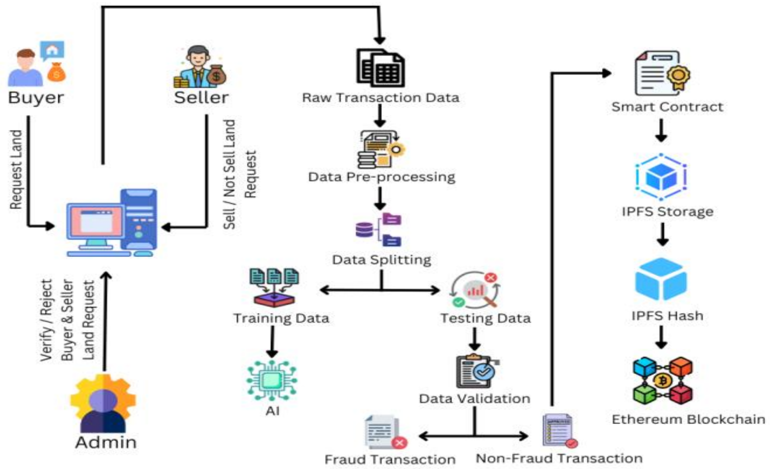

Fig – Architecture diagram

The trained classifier is used to classify the incoming land transactions in real-time, permitting only genuine transactions to move ahead. This process of selective filtering greatly minimizes the storage of unnecessary data in the blockchain.

Logistic Regression

The probability of a transaction being fraudulent is calculated using the logistic function:

$$P(y=1 \mid x)=\frac{1}{1+e^{-(\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n)}} \quad [22]$$

XGBoost Objective Function

$$Obj=\sum_{i=1}^{n} l(y_i,\hat{y}_i)+\sum_{k=1}^{K}\Omega(f_k)$$

l= loss function
Ω= regularization term
f_k= decision tree function

LightGBM Optimization

$$Gain=\frac{1}{2}\left[\frac{G_L^2}{H_L+\lambda}+\frac{G_R^2}{H_R+\lambda}-\frac{(G_L+G_R)^2}{H_L+H_R+\lambda}\right]-\gamma$$

where Grepresents the gradient and Hrepresents the Hessian used for optimal tree splitting in LightGBM.

LightGBM improves training efficiency using Gradient-Based One-Side Sampling (GOSS) and Exclusive Feature Bundling (EFB).The blockchain layer provides immutability and secure record management. The smart contracts are designed to check the validity of ownership information, land transfer, and the authenticity of transactions. Prior to their deployment, the smart contracts are analyzed for vulnerabilities by automated security tools [21] to make them resilient to existing blockchain attacks. After validation, the smart contracts are deployed on the Ethereum test network.To enhance scalability, the original land documents are maintained off-chain through the IPFS. Only the hash of the records is maintained on the blockchain ledger. This AI-blockchain-IPFS process provides a tamper-proof, scalable, and efficient land registry system that can effectively counter fraud and enhance trust in land ownership transactions.

Modules:

The Admin serves as the land inspector and is responsible for authenticating the validity and ownership of the land provided by the sellers. Prior to the listing of a land parcel for sale, the Admin authenticates the ownership documents, checks for government compliance, and approves valid land records. All authentication processes are recorded securely on the blockchain for transparency, accountability, and auditability.

The Buyer module allows users to search only approved land listings by the Admin, providing secure and authentic transactions. Buyers provide identity and financial information to process purchase requests and monitor the status of transactions via the blockchain-based system, providing assurance of trust and data integrity.The Seller module allows landowners to provide ownership documents for authentication. After successful authentication, sellers can list land, determine prices, and process purchase requests. Transactions are allowed only after Admin approval, minimizing the possibility of fraud and ensuring valid land ownership transfer.

Machine Learning for Agriculture and Market Trend Analysis

The Machine Learning component examines agricultural productivity, land value, and market trends based on historical and real-time data. Predictive analysis helps buyers and sellers determine the value of land, when to sell, and where to invest.

Land Verification and Transaction Management Using Blockchain

This component offers safe land records and transactions through the application of blockchain technology.

RESULTS AND DISCUSSION

A. Experimental Setup: The experimental evaluation of the proposed framework of FarmLedger was carried out in order to evaluate the performance of the proposed fraud detection module based on machine learning algorithms and its integration with the proposed blockchain-based land registration system. The experiment was carried out using the Ethereum Fraud Detection dataset obtained through Kaggle [19]. The dataset includes various attributes of blockchain transaction behavior that can be used for fraud detection based on transaction frequency, transfer of ethers, and smart contract interactions. Before training the model, various preprocessing steps were carried out on the dataset in order to improve its quality and performance of the model. The dataset was cleaned by removing duplicate data in order to avoid redundant transaction data. The presence of missing values was also handled accordingly. Feature scaling was carried out using the StandardScaler technique in order to normalize the feature data distribution of the dataset, which is required for machine learning algorithms to ensure convergence of the model. In addition, since fraud detection datasets are generally imbalanced, where fraudulent data is significantly less compared to normal data, SMOTE (Synthetic Minority Oversampling Technique) was applied for balancing the dataset.We divided the complete data set into two sections which included training data and testing data. The team selected an 80/20 data partitioning method for their work. We conducted experiments with various machine learning algorithms to identify the most effective ones for our needs. The algorithms that we used are Logistic Regression and Support Vector Machine and Random Forest and Extreme Gradient Boosting and Light Gradient Boosting Machine. We selected these algorithms to evaluate their performance against the new prediction method that uses the group of models for forecasting.We used Python 3.10 to run our experiments. We used libraries like Scikit-learn and Pandas and NumPy and XGBoost. We built a system to detect fraud. We made it into a service that can make predictions. This service was built on Flask. It talks to the land registration system. We also made a blockchain part using Solidity contracts on the Ethereum test network. We used IPFS to store land documents in a way that is not controlled by one person. We only stored the hash of each document, on the blockchain. This helps keep everything working and makes sure the data is good.

B. Dataset Distribution Analysis: The Ethereum Fraud Detection dataset used in this study includes both legitimate and fraudulent blockchain transaction records. Knowing how these records are distributed is crucial for assessing how well the fraud detection models work.

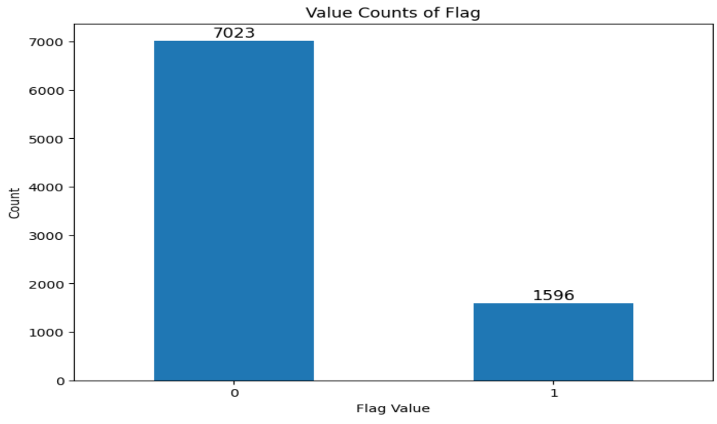

Fig. Distribution of Normal and Fraudulent Transactions in the Dataset

From Fig. above, it is observed that the dataset is imbalanced since normal transactions are dominant in the dataset, while fraudulent transactions are few. Such imbalanced data is common in most fraud detection problems. The imbalance of the data can affect the performance of the classifier since it is prone to be biased towards the majority class. To balance the data, the SMOTE oversampling method was used to balance the data before training the model. This improves the performance of the classifier in detecting fraudulent transactions.

C. Performance Evaluation Metrics

The evaluation of the proposed fraud detection system was conducted using standard classification metrics which included accuracy and precision and recall and F1 Score. The measurement of accuracy shows the correct identification of all transactions which the model predicted as normal or fraudulent. The precision measures the percentage of transactions that were forecasted to be fraudulent that were actually correctly predicted as fraudulent (in other words, precision compares the number of correctly predicted fraudulent transactions to the total number of transactions predicted to be fraudulent). The model performance is measured by recall which shows how effectively the system detects actual instances of fraud. The F1 Score combines precision and recall to create a single statistical measurement which evaluates the classification accuracy of the model.

Accuracy

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

Precision

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

Recall

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

F1 Score

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

TP = True Positive
TN = True Negative
FP = False Positive
FN = False Negative

D. Performance comparison of machine learning models for fraud detection:

Model	Accuracy (%)	Precision	Recall	F1 Score
Logistic Regression	85.6	0.84	0.82	0.83
Support Vector Machine (SVM)	87.9	0.86	0.85	0.85
Random Forest	91.3	0.90	0.89	0.89
XGBoost	93.8	0.93	0.92	0.92
LightGBM	94.6	0.94	0.93	0.93

The table shows us how well different machine learning classifiers work to detect fraud in land transactions when we use the FarmLedger system. We have classifiers like Logistic Regression and SVM.These do a job but they have a hard time learning complicated patterns from a lot of data .The Random Forest classifier is pretty good at finding patterns and making predictions because it uses a lot of decision trees together .The FarmLedger system works with the Random Forest classifier to detect fraud.The XGBoost and LightGBM classifiers are the best at detecting fraud in land transactions using the FarmLedger system. They are good, at fixing mistakes and learning patterns that're not straight forward.The XGBoost and LightGBM classifiers have the accuracy and F1-score when we use the FarmLedger system for fraud detection.The FarmLedger system is really good at finding land deals. This is because it uses machine learning and blockchain technology together. The people who made FarmLedger tried out machine learning models like Logistic Regression, Support Vector Machine, Random Forest, XGBoost and LightGBM. They looked at how each model worked by checking things like accuracy, precision, recall and F1-score.They found out that using models together is better than using just one model. The XGBoost and LightGBM models were really good at finding the answers and getting a high F1-score. This is because these models are good at handling a lot of data and finding patterns. They do this by using something called boosting techniques.

So the FarmLedger system is good at checking land ownership information before it is recorded on a blockchain network. This means that fake information is less likely to be stored on the blockchain network. The FarmLedger system is useful, for making sure that land transactions are honest. The FarmLedger system helps to prevent land deals from being recorded on the blockchain network.

E. Confusion Matrix Analysis

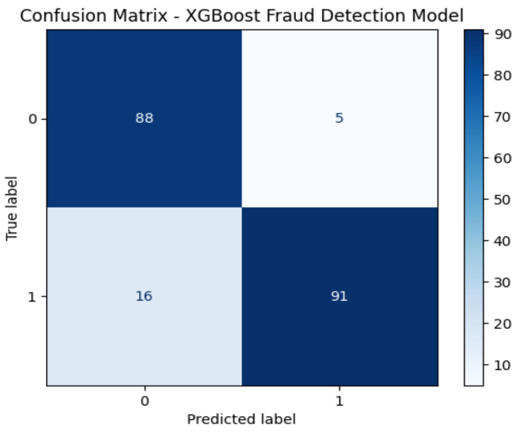

Fig. Confusion Matrix of the XGBoost-Based Fraud Detection Model

The confusion matrix for the XGBoost classifier is shown in Fig. The confusion matrix shows the number of normal transactions classified correctly (True Negatives) and the number of fraudulent transactions classified correctly (True Positives). The results also show that the majority of the fraudulent transactions are classified correctly while only a few are incorrectly classified as either normal or fraudulent. This shows that the classifier is capable of distinguishing between normal and fraudulent blockchain transactions.

F. Feature Importance Analysis

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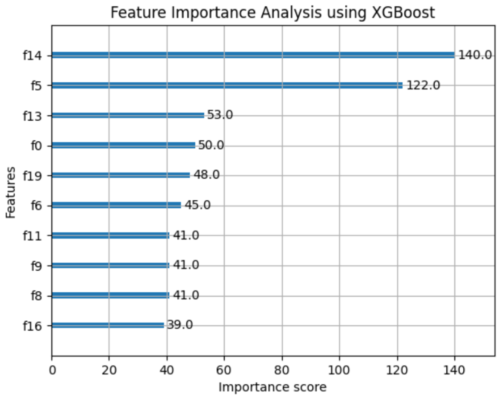

Fig. Feature Importance Analysis using XGBoost

As depicted in Fig. features related to transaction behavior such as ether transfer volume, transaction frequency, and smart contract interaction patterns play an important role in the process of fraud detection. The analysis confirms that blockchain transaction attributes have valuable information that can be utilized for the process of fraud detection.

G. Blockchain Transaction Performance: As part of the machine learning evaluation process, the functionality of the blockchain layer was tested to verify that transactions would be recorded securely and free of tampering. Smart contracts running on the Ethereum network are utilized to automatically verify transactions for land ownership and to save a record of these approved transactions in a distributed ledger.

The use of the Machine Learning Fraud Detection module ensures that no unverified transactions will be recorded in the blockchain. By filtering out any fraudulent transactions prior to being stored in the blockchain, these systems decrease unnecessary computation to provide a more reliable and accurate method of maintaining land records. Additionally, utilizing IPFS for decentralized storage of land documentation greatly enhances system scalability. Rather than storing large architectural files directly on the blockchain, the only data stored in the blockchain ledger is the cryptographic hash of the document while the actual document itself is stored in the IPFS network.

H. Overall System Performance: The results obtained from the experiments show that the FarmLedger system successfully combines the capabilities of artificial intelligence and blockchain technology for the development of secure land registration systems. The machine learning algorithms successfully identify fraudulent transactions before they are added to the blockchain. This ensures that no tampered or invalid land records are added to the blockchain.The results obtained from the experiments show that advanced ensemble learning algorithms such as XGBoost and LightGBM perform better in fraud detection than other machine learning algorithms. The integration of AI technology for fraud detection and blockchain technology for secure data storage ensures a robust system for secure land ownership verification and transaction management.

CONCLUSION

The FarmLedger system provides a safe way to register land in agriculture using blockchain and AI technology. The system provides tamper-proof registration and uses AI to identify fraudulent entries, making it much harder for disputes and fraud to occur. The smart contracts and secure storage of data using IPFS make the land information more reliable and accessible. FarmLedger is ready to lead the way to a more trustworthy and sustainable land registration process in agriculture with its scalability and adaptability.

Future Enhancement: Improvements to the existing system could be made by using more sophisticated AI methods such as deep learning to further improve fraud identification. Real-time monitoring and notification systems can be added to enable faster action by authorities to prevent fraud. The system can be made more compatible with international land registries and GIS systems to improve accuracy. Smart contracts can be updated to keep up with changing legislation

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