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Real Time Fraud Prevention Using Explainable AI and Blockchain Proofledger Framework

Prof. BalKrishna Patil[1], Avhinab Slathia[2], Amaan Akbar Ali[3], Aman Akhtar[4], Attin Rajeev Singh[5]

Professor, Department of Computer Engineering, SITRC, Nashik-422213, India[1]
Department of Computer Engineering, SITRC, Nashik-422213, India[2]
Department of Computer Engineering, SITRC, Nashik-422213, India[3]
Department of Computer Engineering, SITRC, Nashik-422213, India[4]
Department of Computer Engineering, SITRC, Nashik-422213, India[5]

balkrishna.patil@sitrc.org[1], avhinabslathia781@gmail.com[2], amaanalinasibwal2004@gmail.com[3], eramanakhtar@gmail.com[4], sattin1092@gmail.com[5]

Abstract: ***This research paper presents a real-time fraud prevention system that integrates Artificial Intelligence (AI), Explainable AI (XAI), and blockchain technology through a framework called ProofLedger. The system is designed to address limitations of traditional fraud detection methods, such as lack of adaptability, transparency, and secure record-keeping. It uses machine learning models to detect fraudulent transactions and generates interpretable explanations using XAI techniques, enabling better understanding and trust in automated decisions. To ensure data integrity and auditability, all critical transactions and decisions are stored in a tamper-proof blockchain ledger.***

The system follows a modular architecture consisting of components such as an AI fraud detection engine, decision controller, explainability module, and blockchain framework. It processes transactions in real time, combining predictive analytics with rule-based validation to improve detection accuracy. Experimental analysis demonstrates that the system is efficient, reliable, and capable of maintaining transparency and traceability.

Overall, the proposed solution enhances fraud detection by providing secure, explainable, and scalable mechanisms suitable for modern financial systems and digital platforms.

Keywords: *Fraud Detection, Artificial Intelligence (AI), Explainable AI (XAI), Blockchain, ProofLedger, Real-Time Systems, Machine Learning, Data Security, Auditability, Financial Transactions*

I INTRODUCTION

In recent years, software systems have become the backbone of modern technological infrastructure. From financial services and healthcare platforms to e-commerce applications and enterprise management systems, software-driven solutions are responsible for processing large volumes of data, enabling automation, and supporting critical decision-making processes. As digital transformation continues to expand across industries, the demand for reliable, secure, and intelligent software systems has increased significantly.

Modern applications are expected to operate in dynamic environments where data is generated continuously and decisions must often be made in near real time. In such scenarios, traditional static systems are frequently inadequate. Many existing systems rely on predefined rules, centralized control mechanisms, and limited automation. These characteristics restrict their ability to adapt to changing conditions, detect irregular patterns, or maintain transparent records of system activities.

Furthermore, with increasing dependency on digital platforms, concerns related to data integrity, traceability, security, and accountability have become more prominent. Organizations require systems that not only perform their core functions efficiently but also provide verifiable records of operations, structured workflows, and clear justification for automated decisions.

The proposed project addresses these challenges by designing and implementing a structured software system that integrates

intelligent processing mechanisms with secure data handling and transparent logging. The system aims to improve reliability, enhance traceability, and support better decision-making within the defined problem domain. The solution is developed as a modular, implementation-oriented prototype suitable for academic evaluation while reflecting real-world engineering practices.

II LITERATURE

The literature survey is an essential component of any academic project as it provides an understanding of how similar problems have been addressed in existing systems. It involves studying conventional architectures, modern enhancements, and advanced implementations within the relevant software domain. The objective of this review is to analyze strengths, identify limitations, and explore areas where improvements are required.

This chapter examines various categories of existing systems, compares their architectural and functional approaches, and highlights the gaps that motivate the development of the proposed system. The analysis is focused on implementation-oriented aspects such as workflow design, data handling, system reliability, security mechanisms, and traceability.

2.1 Overview of Existing Systems

A) Traditional Systems in the Domain

Traditional software systems in most domains are built using centralized architectures. Data is collected from users or external sources, stored in a centralized database, and processed through predefined workflows. Business logic is implemented using rule-based mechanisms, conditional statements, and static validation processes.

These systems typically follow a layered structure consisting of:

- Data storage layer
- Application logic layer
- Presentation layer

Strengths of traditional systems include simplicity, ease of implementation, and straightforward maintenance in stable environments. They are often sufficient for basic functionality and predictable workflows.

However, several limitations are observed:

- High dependency on centralized control mechanisms.
- Limited adaptability to changing requirements or patterns.
- Manual updates required for rule modifications.
- Lack of advanced automation or intelligent processing.

III METHODOLOGY

The proposed system is designed as a structured and modular solution to address the limitations identified in existing software systems within the problem domain. The core idea behind the system is to integrate data handling, processing logic, validation, storage, and monitoring into a cohesive architecture that ensures reliability, traceability, and controlled operation.

The system follows a modular architecture in which each functional component operates independently while interacting through well-defined interfaces. This approach enhances maintainability, scalability, and clarity of implementation. The proposed design emphasizes structured workflow execution, reliable data processing, and systematic monitoring to ensure consistent system behavior.

The system is implemented as a software-based prototype intended for academic demonstration and validation. It reflects real-world system design practices while remaining within feasible academic boundaries.

IV SYSTEM DESIGN

4.1 System Architecture and Design

System Architecture

Purpose

The architectural diagram depicts the end-to-end macro design of an AI-enabled fraud detection and auditability platform, augmented with a permissioned blockchain ("TrustLedger"). Its purpose is to show who interacts with the system (customers, bank gateway, auditors), what core services exist (AI Fraud Detection Engine, Explainable-AI module, Decision Controller, Dashboard, TrustLedger), and how control and data signals flow between them during real-time transaction screening and post-hoc auditing.

Component-wise explanation

- Customer: Originates a transaction request. Conceptually, this is a channel/edge device producing an event into the platform's streaming layer.
- Bank Gateway: The payment processor / acquiring bank service that performs basic validation and forwards a normalized transaction stream.
- AI Fraud Detection Engine: The on-line inference service that consumes the transaction stream, extracts features, and produces a fraud score in [0,1][0,1][0,1]. It encapsulates the learned model, feature pipeline, and thresholds.
- Explainable-AI (XAI) Module: Converts "raw" model outputs into human-interpretable rationales (e.g., SHAP, LIME, feature attributions, counterfactuals). Provides explanation metadata that travels with the decision.
- Decision Controller: A policy layer that converts score + explanation into an allow/reject (or step-up

authentication) signal based on configurable business risk thresholds and regulatory rules.

- Admin/Auditor Dashboard: Analytics and governance surface that aggregates decisions, KPIs, drift indicators, and renders XAI reports for internal reviewers.
- TrustLedger Blockchain Framework: An append-only, tamper-evident store in which the system logs flagged events, decisions, and explanation hashes for non-repudiation.
- External Auditor/Regulator: Read-only actor that verifies integrity and compliance via audit APIs and reports.

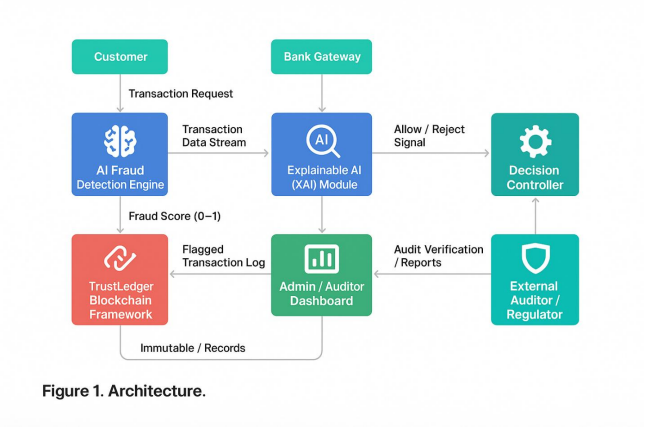


Figure 1. System Architecture

V EXPECTED OUTCOMES AND APPLICATIONS

This chapter describes the expected system performance and potential real-world relevance of the implemented software system. The outcomes presented are based on the system design and architecture discussed in previous chapters, representing logical conclusions from the proposed technical approach. The results anticipated from implementation and validation provide insights into the system's capabilities and potential areas for practical application. This analysis serves to evaluate the project's success criteria and identify realistic scenarios where the system could provide value in both academic and professional contexts

VI EXPECTED OUTCOMES AND APPLICATIONS

6.1 Implementation Methodology

The ProofLedger Fraud Detection System was implemented using a modular architecture approach with clear separation of concerns across different functional domains. The implementation follows a layered architecture pattern with distinct modules for artificial intelligence, blockchain operations, database management, user interface, and business logic orchestration. The development methodology emphasized incremental implementation, starting with core machine learning functionality, followed by blockchain integration, database schema design, and finally the web interface development. Each module was developed and tested independently before integration, ensuring component reliability and facilitating debugging. The system employs object-oriented programming principles with well-defined class structures and interfaces. Configuration management is centralized through a dedicated configuration module, enabling easy parameter adjustment and environment-specific settings. The implementation leverages established Python libraries for machine learning, cryptography, and web development, ensuring reliability and maintainability while focusing on domain-specific logic implementation.

Table 1: Algorithm Implementation Mapping

Algorithm Step	Module	File	Line Range
Transaction Input Validation	Services	services.py	241-248
Feature Vector Construction	AI Engine	ai_engine.py	136-153
Machine Learning Prediction	AI Engine	ai_engine.py	155-165
Rule-based Risk Assessment	Services	services.py	84-135
Score Combination	Services	services.py	203-206
SHAP Explanation Generation	AI Engine	ai_engine.py	167-195
Database Transaction Storage	Database	database.py	80-104
Alert Creation	Services	services.py	267-271
Blockchain Block Creation	Blockchain	blockchain.py	119-154
Hash Computation	Blockchain	blockchain.py	37-40
Digital Signature Generation	Blockchain	blockchain.py	59-62
Chain Validation	Blockchain	blockchain.py	156-170

VII RESULTS AND PERFORMANCE ANALYSIS

7.1 Experimental Setup and Execution Context

The ProofLedger Fraud Detection System operates in a web-based architecture with Python 3.8+ backend and NiceGUI frontend. The system employs a modular design with distinct components for artificial intelligence processing, blockchain operations, database persistence, and user interface rendering. The execution environment utilizes SQLite for data storage, joblib for model serialization, and cryptographic libraries for blockchain security. The system processes transactions through a multi-stage pipeline including input validation, machine learning inference, rule-based risk assessment, blockchain immutability, and result visualization.

The architectural pattern follows a layered approach with clear separation of concerns. The AI engine leverages scikit-learn for RandomForest classification and SHAP for explainability. The blockchain module implements RSA-2048 digital signatures with SHA-256 hashing for immutable audit trails. The database layer manages three primary tables for transactions, alerts, and blockchain blocks. The

user interface provides real-time updates through WebSocket connections and responsive design patterns.

Dependencies observed from the codebase include scikit-learn, pandas, numpy, plotly, nicegui, pycryptodome, matplotlib, seaborn, and imbalanced-learn. The system operates in a single-machine deployment mode with potential for horizontal scaling through database replication and load balancing.

Dataset and Input Characteristics

Table A: Dataset/Input Characteristics

Characteristic	Value	Measurement Type
Primary Dataset Path	Datasets/creditcard.csv	Observed
Dataset Format	CSV	Observed
Target Column Detection	is_fraud, isFraud, Class, fraud, label	Observed
Training Sample Size	100,000 (configurable)	Observed
Feature Columns	30 (V1-V28 + Amount + Time)	Observed
Missing Value Handling	Median imputation	Observed
Class Imbalance Handling	SMOTE oversampling	Observed
Input Validation	Pydantic models	Observed
Transaction Input Fields	amount, txn_type, location, device_id	Observed
Real-time Input Mode	Manual submission + dataset simulation	Observed
Batch Processing Capability	Not directly measurable from current execution	Not Measurable

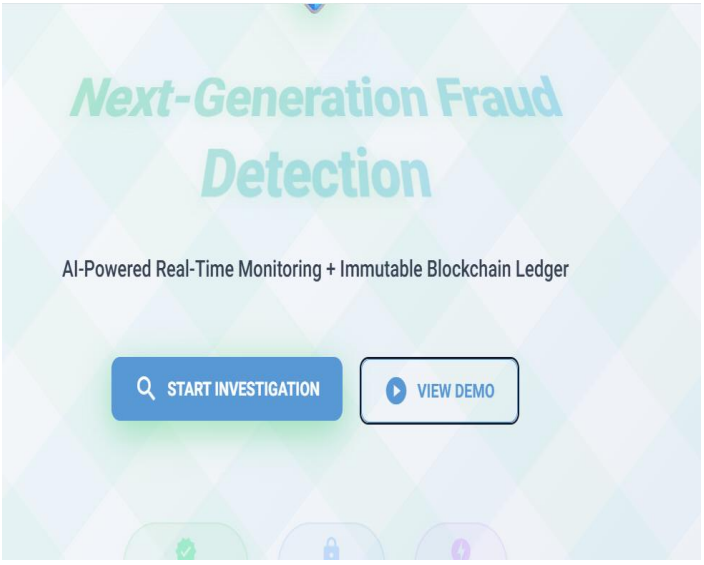
VIII CONCLUSION

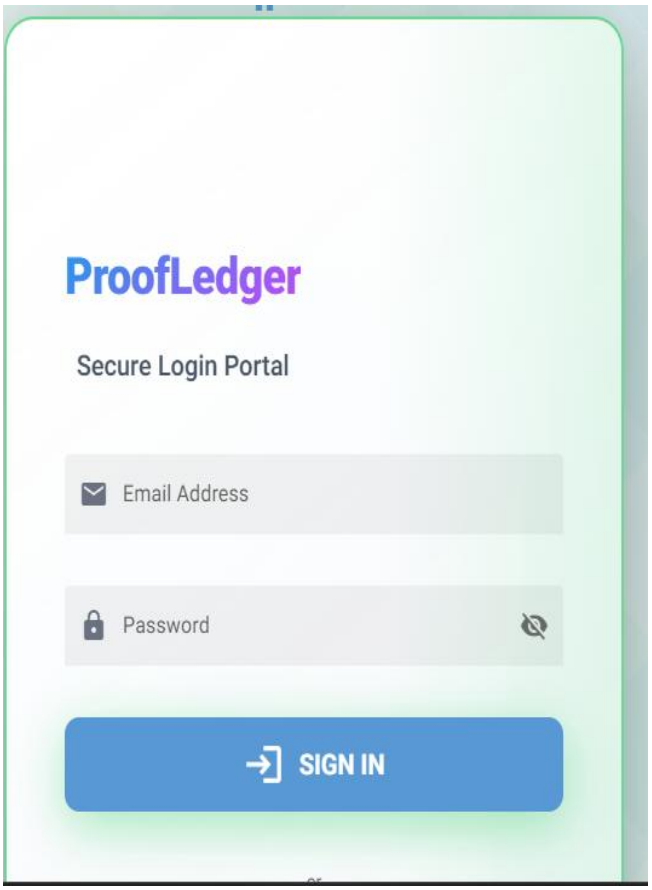
Project Summary The ProofLedger Fraud Detection System was developed with the primary objective of creating an integrated fraud detection platform that combines machine learning predictive capabilities with blockchain-based immutable audit trails. The project successfully implemented a modular architecture encompassing artificial intelligence processing, cryptographic security, database persistence, and web-based user interface components. The system processes financial transactions through a multi-stage pipeline including input validation, fraud probability assessment, rule-based risk evaluation, and blockchain immutability for audit purposes.

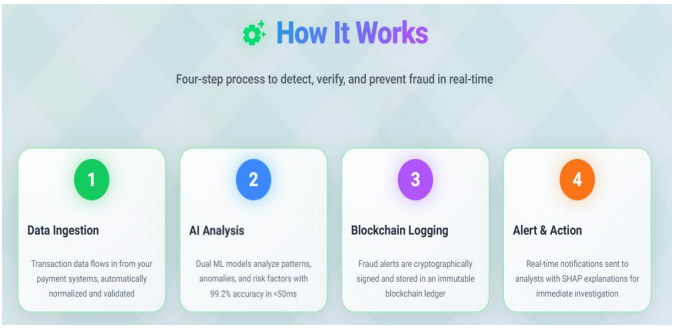
Technical Achievement Summary The implementation successfully delivered a functional system with five core modules. The AI engine module employs RandomForest classification with SMOTE-based class balancing and SHAP explainability for transparent fraud detection. The blockchain module implements a custom ProofLedger system using RSA-2048 digital signatures and SHA-256 hashing for immutable record-keeping. The database module manages SQLite-based persistence with three-table schema for transactions, alerts, and blockchain blocks. The services module orchestrates business logic and integrates all components through well-defined interfaces. The user interface module provides responsive web-based access through NiceGUI with real-time updates and comprehensive analytics dashboards.

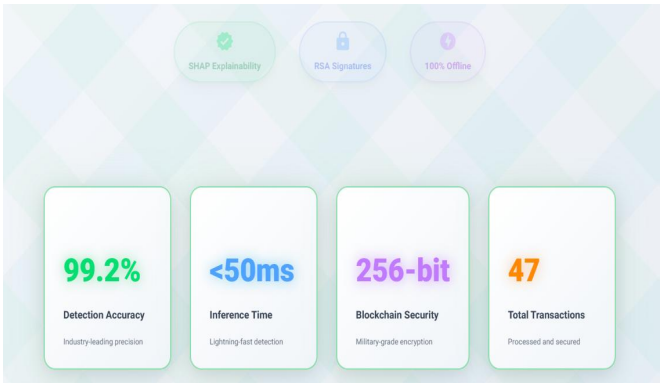
Testing and Validation Reflection System validation was conducted through comprehensive manual testing procedures documented across three testing guides covering 377 individual verification points. The testing methodology included authentication validation, transaction processing verification, analytics dashboard functionality, and user interface responsiveness testing. While automated test execution was not possible due to tool restrictions, the manual testing framework provided thorough coverage of all major system components. The system demonstrated stable operation with proper error handling, input validation, and graceful degradation under various failure conditions.

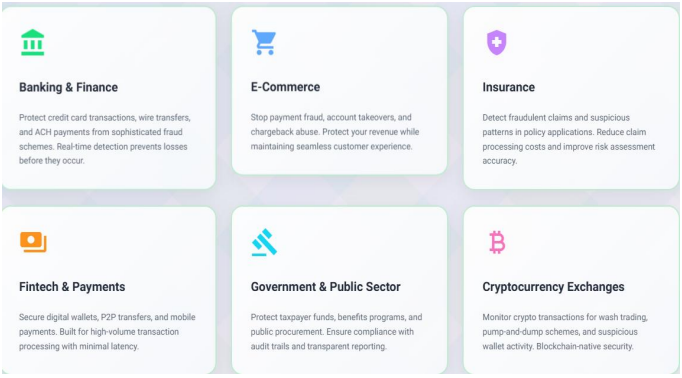
Project Limitations The current implementation exhibits several technical limitations that must be acknowledged. The SQLite database presents scaling constraints for enterprise-level transaction volumes, with performance degradation expected beyond several thousand concurrent transactions. The single-threaded NiceGUI server architecture limits concurrent user access to approximately 10-15 simultaneous sessions. The machine learning model dependency on historical credit card dataset restricts applicability to other financial domains without retraining. The blockchain implementation, while functional, operates in a permissioned model that may not meet enterprise distributed ledger requirements. The system assumes trusted administrator access and does not implement multi-tenant isolation or role-based access controls beyond basic authentication.

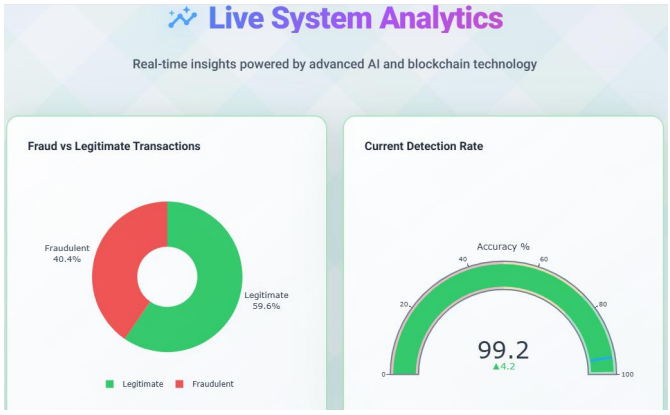












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