

Quantum Machine Learning Model for Credit Card Fraud Assessment with Ensemble Learners

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Abstract:

Credit card frauds are placing a great challenge over financial systems. The traditional rule based systems often fail to handle sophisticated fraudulent techniques. In this model we are applying Feed forward Neural Networks with a multi-layer perceptron to identify imbalanced transactional data with advanced preprocessing, scaling and classification. This model can interpret complex transaction patterns effectively to minimize misclassification. On the other hand Quantum techniques improve the ability to data ETL process over IoT devices in banking systems. The Quantum Machine Learning adoption improves the processing capacity with great minimization of computational devices size. The Quantum Computing delivers high precision and accuracy with fast processing of digital information.

Index Terms—Quantum Computing, feed Forward, Neural Networks, Classification, Q-Bits, Fraudulent.

Introduction

Digital banking systems supporting e-commerce majorly suffering from credit card fraudulent activities [6]. Machine Learning and statistical models somehow offense suspicious transactions but increased data growth and complex patterns of attacks placing great challenges over these systems [4]. Intensive deep learning models inspect multiple layers from complex data patterns helpful to estimate the behavior of malicious attacks [7]. Some models developed to support spatial transaction patterns analysis for fraud pattern detection using CNN [2]. RNN models widely suitable for continuous analysis of sequential transaction flows with LSTM they are capable to hold long-term transaction behavior [3]. Latest Quantum Computing technology becomes replacement for traditional fraud detection systems [9]. These Quantum systems exhibit high parallelism in computation millions of transactions simultaneously to identify malicious patterns in transactions [1]. Quantum computing amplitude estimation algorithms can improve the Monte Carlo sampling rate and accuracy which influences the current financial methods [11]. Recent investigations identified that Block chain usage in banking services improves AIS quality, customer relationships, strategic performance as well as operational efficiency [5].

I. MODEL ARCHITECTURE

Figure 1 is the integrated architecture of Credit Card Fraud detection system. Three major entities are fused for extreme accuracy and precision in fraud detection.

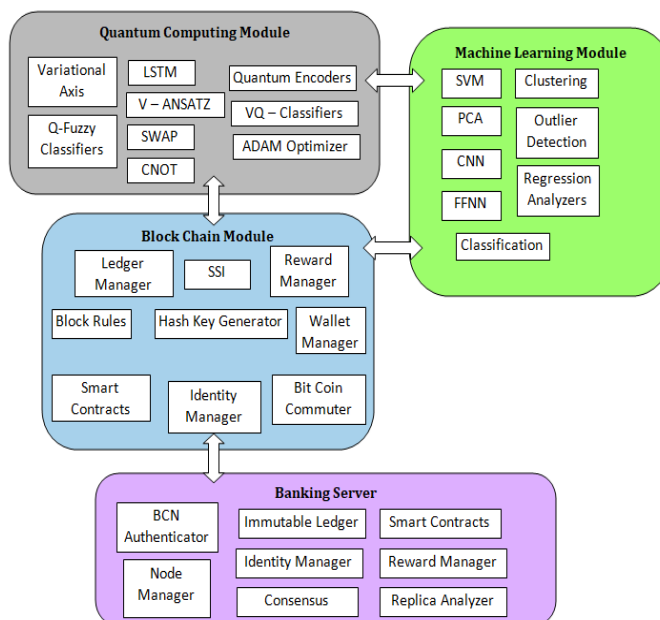


Fig 1: QML Credit card fraud assessment system

A. Quantum Computing Module

A collection of 'Variational Quantum Classifiers' supporting Quantum Support Vector Machines (QSVM) analyze the credit card data sets related to transactions to identify fraud patterns. These classifiers performance is high and precision is extended compared to classical machine learning methods. To handle real-time financial networks Quantum Restricted Boltzmann Machines (ARBM) along with Quantum Federated Neural Networks (QFNN) used. The quantum superposition techniques applied over these modules can explore high dimensional spaces with high precision and accuracy in detecting anomalies.

B. Blockchain Module

Quantum key distribution technique is more secured than available data sharing techniques over BCN. The Smart Contracts somehow provide validation checks over transactions. Introducing Quantum cryptography improves the quality of smart contracts to resist ultra modern cyber attacks. To validate the blocks in BCN Consensus manages authentication summaries with hybrid quantum GNNs fraud detection becomes more effective. Other services like reward-manger, wallet-manager, Identity-manager and Bit coin-Commuter influenced with quantum computing Superposition (improves parallelism in processing), Entanglement (performs anomalies detection, pattern evaluation), Interference (Amplifies the ML algorithms input and output capacities).

C. Machine Learning Module

Machine learning module comprises with various machine learning techniques to detect

suspicious transactions fraudulent activities among credit card transactions. Logistic regression and decision trees useful to classify the fraud patterns effectively, also Random Forest supports massive data with reduced overfitting. The Gradient boosting techniques gives high accuracy in fraud anomaly detection. Neural Networks supports complex and unknown pattern analysis using FFNN, CNN and RNN to predict future attacks and their behaviors.

D. Banking Server

Primary authentication system to authenticate BCN clients. Manage immutable ledgers with smart contracts. Identity manager enables various rules and policies to BCN services over consensus. The replica manager assists with copies of node transactions. Node manager governs the communication and coordination among several BCN nodes effectively with reward manager module.

II. DATA STAGING

During the data staging phase various data cleaning techniques applied over ccard.csv, ctrans.csv files. Due to high imbalanced data existence examining data shape, missing values, noise and scaling differences corrected. Outlier detection applied over 'Amount', 'Time', 'Transaction Anomaly' and 'frauds' using IQR Z-Score technique.

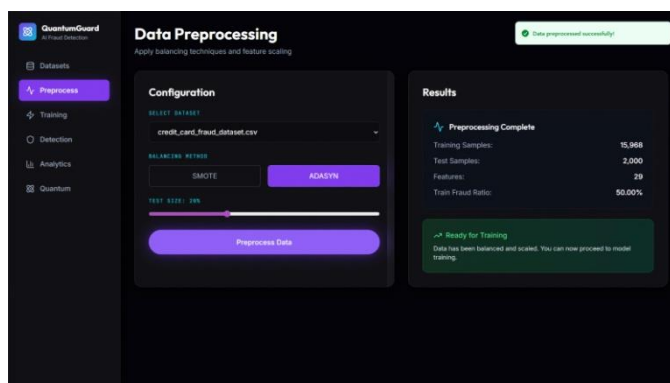


Fig 2: Quantum Credit card fraud detection system data preprocessing

To handle transaction patterns if necessary some new features are created using feature engineering approaches. The Data sets are splitted into training data and testing data 80:20 proportion base. The imbalanced data set handling metrics like Precision, Recall and F1-Score applied minority class performance.

Also advanced metrics such as AUC-PR, G-Mean and Mathews Correlation Coefficient are modern techniques to fine tune large real-time data sets like credit card transactions.

III. METHODOLOGY

Quantum Circuits are high precision oriented compared to classical model to handle fraud patterns in credit card transactional data sets. Most typical components highly employed Variation Quantum Classifiers and Quantum Support Vector Machines combinational circuit as shown in figure 3.



Fig 3: Quantum Circuit diagram for Credit Fraud Detection

The rotations applied over VQCs and entangling results new unseen patterns from data. The mapping of data features with qubits and rotations selected depending on the data encoding formats. The feature maps are amplified with alterations in single qubit rotations and binary qubit rotations. On other hand QSVM uses quantum kernels to generate high dimensional Hilbert spaces with computation similarity. Highly support non linear separation to identify wide range of fraud patterns among data. The ZZ-feature map is widely accepted quantum kernel encoding for mapping classical data into quantum states using Pauli-Z evolution principles.

QVSM Fraud detection Algorithm

- Step 1:* Initialize the Hadamard Gate (H) on all Qubits
- Step 2:* Start rotations $R_z(X_i)$ and $2\pi\phi(x_j)$
- Step 3:* Apply Entanglement controlled by ZZ-feature map for linear qubits $H \otimes 3 \rightarrow [RZ(x_0), RX(2\pi\phi(x_1, x_2))]$
- Step 4:* Estimating non linear kernels using $K(x, y) = |\langle \varphi(x) | \varphi(y) \rangle|^2$
- Step 5:* Combine the features for knowledge pattern generation
- Step 6:* Identify new patterns with entanglement sequences
- Step 7:* Generate the output factors with normalization scores

The XG-Boost algorithm performs well over high scaled feature data sets well. The transactions data set with 12 features, after dimensionality reduction done using PCA which is faster and flexible to handle linear data features.

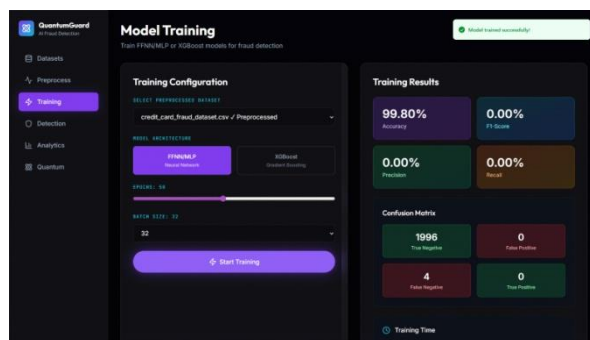


Fig 4: Model Training using XG-Boost

The positive weight scaling approach is used for XG-Boost to handle imbalanced data effectively. The sampling performance can be tuned using SMOTE and under sampling approaches is another way to resolve imbalance issue in data set. After model generation several accuracy metrics are considered to evaluate model performance. The ROC-AUC, Precision, Recall, F1-score and confusion matrix are widely accepted.

The default threshold is '0.5' which is reduced to '0.2' hence lower threshold catches more fraud patterns with high recall. The XG-Boost model is highly adaptive to ensemble modeling to support modern challenges over real-time fraud pattern classification.

IV. FRAUD DETECTION SCENARIO

The process of fraud detection in quantum computing enabled financial systems follows staged process

- 1: Fraud detection using classical logistic regression

$$P\left(y = \frac{1}{x}\right) = \frac{1}{1 + e^{-w^T x}}$$

Where $x \rightarrow$ transactions;

$w \rightarrow$ weights

$P \rightarrow$ probability of fraud.

- 2: Loss Function useful to find entropy for classification

low entropy leads best classification of frauds.

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

The ML generated data must be encoded into quantum states to support quantum computing. Two modes of encoding to be applied for data.

Amplitude Encoding used for amplifying the data granularity and effective to handle high dimensional data.

$$|x\rangle = \sum_{i=0}^{2^n - 1} x_i |i\rangle$$

It maps normalized classical transactions into quantum boosted states. Enhance data loading into quantum circuits. Special Fidelity based Quantum Auto-encoders (FiD-QAE) employed for fraud transaction detection over financial transactions.

Angle Encoding based on Pauli's principles, maps classical transaction features into single qubit rotational angles RY (θ). Method in Variational Quantum Classifiers (VQCs) used to map features into Hilbert spaces. VQCs are subjected to angular entanglement for measuring probabilities for fraud prediction through cross-entropy loss functions and Adam optimization models. Simple to implement but low accuracy and precision.

$$|\psi(x)\rangle = \bigotimes_{i=1}^n R_{y_i}(x_i)|0\rangle$$

4: An unitary transformation needed for Quantum Circuit Transformation to prepare circuit model.

$$|\psi(\theta)\rangle = U(\theta) |x\rangle$$

5: Variational Quantum Classifier (VQC) is core to Quantum based machine learning systems. They use cost functions or cross entropy for identifying impurity in transactions data. Gradient Optimization can be applied to improve quality in fraud pattern identification.

5: Quantum Kernel Method maps quantum features with Gram matrices in high dimensional Hilbert spaces enhancing fraudulent transaction separation using SVM models. This approach effectively handles non linear patterns anomalies.

V. RESULT ANALYSIS

We performed performance analysis over various machine learning classification algorithms for fraud transaction prediction. The figure 4 shows the classification techniques performance analysis.

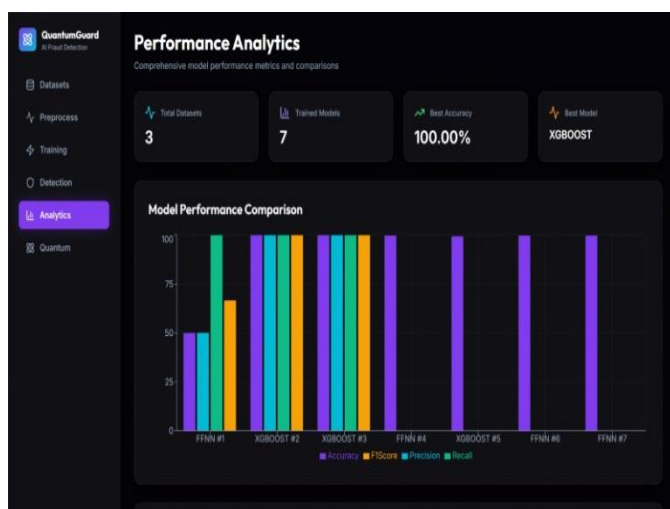


Fig 5: Comprehensive Analysis of ML Techniques in QCCFDS

Our analysis study proved that XG-Boost based variational algorithms shown high performance in handling credit card transaction data. These large scale data places more

challenges to classification and prediction algorithms. Classical decision trees are easy and interpretable but faces Overfitting problem.

Logistic regression shown performance over high feature engineered data only. Computationally fast over low fraud patterns. Random forest enables ensemble feature with bagging approaches. They show high accuracy, low Overfitting and handles non linear data. They are slow but can handle large data.

Gradient Boosting is low suitable due to requirement of high tuning to handle complex patterns. SVM on the other hand effective to handle high dimensional data very effective in linear class Separability but poor in large data handling also kernel tuning is a bit tricky. FFNN are well suitable where unpredictable new fraudulent activities occurring more over transactions. They are expensive to train but capable to handle extreme large data sets. In scalability perspective it is proved that FFNN and XG-Boost are more flexible and classifies moderate real data also.

TABLE 1. Ensemble Methods Comparison

Methods	Accuracy	Feature
<i>XG-Boost, LGBM, Stacking</i>	94.3 – 99.6	Effective in handling imbalance of transactions
<i>VQC, QRBF, Voting</i>	94.3 – 98.4	Effective in handling real time transactions
<i>QSVM, VQC, Stacking</i>	96.3 – 98.7	Effective in handling real time transactions and false alarms

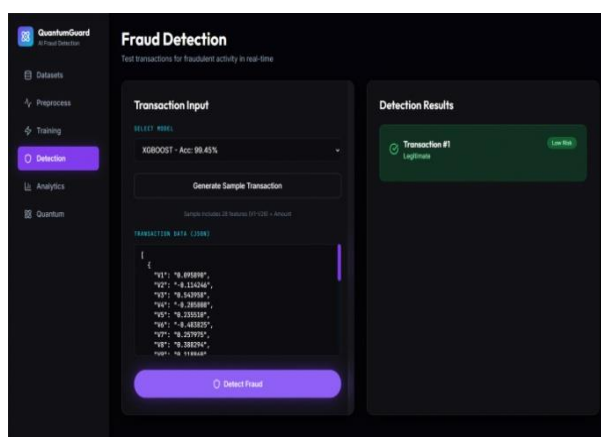


Fig 6: Fraud events Detection XG-Boost Performance

Figure 6 shows the system detected fraud transaction tokens summary with XG-Boost performance metrics. The system is flexible to select variant classification techniques and examine their performance through user interface.

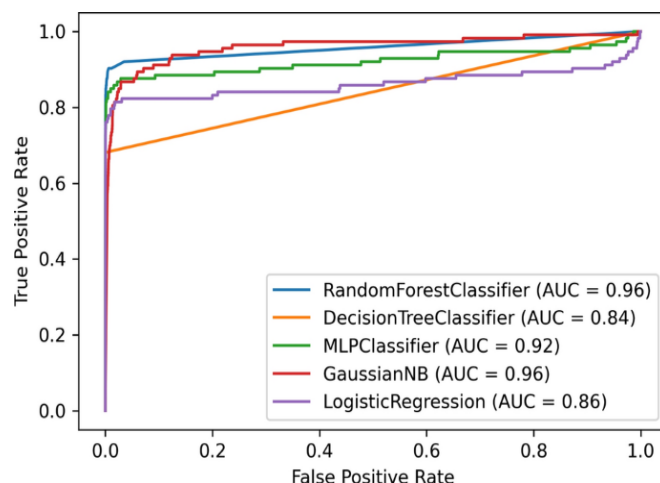


Fig 7: ROC over various classifiers in credit card fraud detection

Figure 7 show that ensemble approaches improve the fraud pattern detection in large scale real time credit card transactions well. RBF networks helps to effectively find the probability of fraud activities over samples. SMOTE improves resampling techniques. XG-Boost exhibits 99.6% accuracy under various operational characteristics. Stacking approaches are widely applicable among polymorphic fraud patterns. AUC-ROC for stacking approaches gives 94.3%accuracy with F1-Score of 0.84. Hence ensemble methods are highly acceptable in real time environments with high robustness to risks.

VI. CONCLUSION

In this paper we focused over a hybrid model which combines quantum computing features with machine learning approaches. Modern financial system demanding high scale precision over transactions with huge dimensionality.

The framework model is highly adoptable for banking systems which are integrated with Block Chain technology. Proposed model is scalable to support medium to high sensitive credit card fraud detection and classification systems. The modules supporting Block Chain features are adoptable to any financial environment. In future we need to focus over network security techniques adoption into this model for improving the quality of digital banking services.

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