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A Secure Machine Learning Model for Drug Authentication

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Abstract: *This study presents a secure machine learning model for drug authentication to combat the proliferation of counterfeit pharmaceuticals. A web-based system was developed by integrating a FastTree binary classification model in ML.NET with biometric facial recognition for user authentication. The system enables real-time verification of pharmaceutical products using structured metadata, including batch numbers, expiration dates, manufacturer identifiers, and barcodes. A dataset obtained from the U.S. Food and Drug Administration's OpenFDA repository was used for model training and evaluation, with preprocessing implemented through a C# schema class. To enhance system security and prevent unauthorized access, a facial recognition module was incorporated as an additional authentication layer. Performance evaluation using 10-fold cross-validation yielded strong results, achieving 97.8% accuracy, an F1-score of 96.8%, and an AUC of 0.981. The proposed system provides a lightweight, scalable, and secure framework that integrates machine-learning-based drug authentication with biometric access control. This approach enhances the reliability, integrity, and security of pharmaceutical verification systems. Future work may explore larger datasets and blockchain integration for improved traceability.*

Keywords: Drug Authentication, Counterfeit Drug Detection, Machine Learning, Biometric Authentication, Pharmaceutical Supply Chain

I. INTRODUCTION

In recent years, the pharmaceutical industry has faced increasing threats from counterfeit medications, fraudulent practices, and the limitations of traditional drug authentication methods. These challenges pose serious risks to public health, reduce confidence in healthcare systems, and weaken regulatory oversight. The continued infiltration of counterfeit drugs into legitimate supply chains remains a global concern, with harmful consequences for patients, healthcare providers, and pharmaceutical manufacturers. This underscores the urgent need for advanced technologies that ensure drug authenticity and traceability [1].

Conventional approaches, such as barcode scanning and serialization, are often limited in their support for real-time verification and are vulnerable to manipulation. As a result, counterfeiters continue to exploit these weaknesses. Additionally, identity verification within regulatory systems remains a challenge, as manual processes are prone to errors and forgery. Ensuring that only authorized personnel have access to drug authentication systems is essential for maintaining integrity and accountability [2].

Machine Learning (ML), a subset of Artificial Intelligence (AI), provides a promising solution by enabling the analysis of large datasets to detect patterns and anomalies associated with counterfeit drugs. This supports accurate and real-time classification of pharmaceutical products [3]. Furthermore, biometric technologies such as facial recognition enhance identity verification and reduce the risk of unauthorized access [4] [5].

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This study proposes a secure ML-based framework for drug authentication, integrated with biometric identity verification, to improve accuracy, security, and trust within the pharmaceutical supply chain.

The major contributions of this study include:

- Development of a machine learning–based drug authentication system using ML.NET.
- Integration of biometric facial recognition for secure identity verification.
- Implementation of a real-time web-based pharmaceutical verification platform.
- Performance evaluation using 10-fold cross-validation to ensure reliability.

II. STATEMENT OF THE PROBLEM

The global spread of counterfeit pharmaceutical drugs has emerged as one of the most critical public health crises of our time. According to [6], approximately 10% of medical products in low- and middle-income countries are substandard or falsified, leading to treatment failures, drug resistance, and even loss of lives. Existing approaches such as serialization, barcoding, and QR-code verification are often reactive, fragmented, and vulnerable to replication by sophisticated counterfeiters. In many cases, these systems cannot reliably differentiate between authentic and fake packaging, thereby creating loopholes in pharmaceutical supply chains.

Another concern is that access to drug verification systems can be compromised by unauthorized individuals. Without proper safeguards, counterfeiters or unverified users may exploit these systems to register or distribute falsified drugs. To address these challenges, this study develops a secure machine learning model that focuses primarily on drug authentication by classifying pharmaceutical products based on packaging and product metadata, while incorporating biometric identity verification as a secondary layer of protection against unauthorized access.

To address these challenges, this study develops a secure machine learning (ML) model for drug authentication with integrated identity verification. Built using ML.NET, Microsoft's open-source ML framework, and deployed in an ASP.NET-based web application, the system incorporates the FastTree binary classification algorithm, a high-performance, gradient-boosted decision tree model optimized for accuracy and speed. This model classifies pharmaceutical products based on batch number, expiration date, and manufacturing origin, and verifies user identity through biometric facial recognition. The unified model aims to improve real-time classification accuracy, reduce unauthorized access, and adapt to evolving counterfeiting techniques, all while maintaining lightweight computational requirements for resource-limited environments.

III. REVIEW OF RELATED WORKS

[7] proposed PharmaChain, a blockchain-based system for provenance verification in the pharmaceutical supply chain. The work was motivated by the need to mitigate counterfeit drug risks by enabling transparent and immutable tracking. The objective was to design a distributed ledger platform that enhances accountability among supply-chain actors. The work contributed to knowledge as follows:

It demonstrated that blockchain can provide a tamper-resistant framework for provenance verification in pharmaceuticals.

It offered a scalable model adaptable to other high-value supply chains.

A limitation of the study was its primary focus on prototype evaluation without extensive real-world deployment, leaving a gap for practical testing in large-scale pharmaceutical environments.

[8] introduced BE-AC, a blockchain-based anti-counterfeiting traceability solution for the pharmaceutical industry. The motivation was to enhance the verification of drug authenticity in supply chains. The objective was to integrate blockchain technology with access control mechanisms to ensure reliable traceability. The work contributed to knowledge as follows:

Designed a blockchain model combining traceability with access control.

Demonstrated improved reliability in counterfeit prevention.

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A limitation was scalability challenges in handling large-scale pharmaceutical datasets, creating a gap for future optimization of blockchain performance in high-volume environments.

[9] developed an enhanced blockchain-based verification system for drug supply chains. The motivation was the widespread circulation of counterfeit drugs. The objective was to create a framework that supports end-to-end verification of pharmaceuticals.

The work contributed to knowledge as follows:

Designed a blockchain framework for consumer-level verification.

Highlighted transparency benefits in the supply chain.

A limitation was the absence of IoT integration, which hindered broader scalability and highlighted a research gap in combining blockchain with IoT for real-time monitoring.

[10] proposed a blockchain-based prototype for authenticating counterfeit medicine. The motivation was to strengthen supply-chain security using immutable ledgers. The objective was to evaluate blockchain for real-time authentication of medicines. The work contributed to knowledge as follows:

Presented a proof-of-concept blockchain model.

Showed blockchain's feasibility for authentication tasks.

A limitation was that the study remained at the prototype level without full scalability testing, highlighting the need for field validation in real-world supply chains.

IV. METHODOLOGY ADOPTED

The methodology adopted for this research work is the Prototype Software Development Model, which is most suitable for designing and implementing innovative systems that require iterative refinement. This choice was motivated by the exploratory nature of the study, which integrates drug authentication and identity verification into a unified platform. The prototype model enables the progressive development of the machine learning classification model, biometric facial recognition, and the web-based ASP.NET application, incorporating feedback at each stage to enhance performance and usability.

The research process followed a structured approach. First, relevant datasets on pharmaceutical packaging and counterfeit identifiers were collected and pre-processed for training using the FastTree binary classification algorithm in ML.NET. This stage ensured that the machine learning model could reliably distinguish between genuine and counterfeit drug packaging. Next, a facial recognition module was implemented to serve as the identity verification component, leveraging biometric authentication to secure access to pharmaceutical data. These two modules were then integrated into an ASP.NET web-based system to provide a unified, real-time solution for both drug authentication and user identity verification.

Finally, the system was tested and evaluated to determine its effectiveness in detecting counterfeit pharmaceutical packaging and preventing unauthorized access. The evaluation focused on model accuracy, system reliability, security performance, and real-time responsiveness.

V. PROPOSED SYSTEM

The proposed system addresses the limitations of existing drug authentication methods by integrating advanced machine learning and biometric technologies into a unified, secure, and real-time platform. At its core, the system introduces a machine-learning-based classification model, specifically the FastTree binary classification algorithm in ML.NET, to detect counterfeit pharmaceutical products. This model analyzes drug packaging data and product identifiers, enabling intelligent detection of fraudulent or forged drugs with higher accuracy compared to manual inspection.

In addition to drug authentication, the system incorporates biometric facial recognition for identity verification. By leveraging facial recognition technology, users are securely authenticated before accessing pharmaceutical data, ensuring that only authorized individuals can perform drug verification and related transactions. This dual approach

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addresses both product authenticity and user identity validation in a single workflow, reducing impersonation risks and unauthorized access.

A notable feature of the system is its ability to log and track verification activity. When a user verifies a drug, both the verified drug and the verifying user's information are securely recorded in the database. This functionality provides an auditable history of verification events, supporting accountability, traceability, and data-driven decision-making for pharmaceutical stakeholders.

The system further integrates these components into a web-based ASP.NET application designed to operate in real time. This ensures a seamless user experience, with drug authentication and identity verification processed simultaneously in the same environment. The real-time capability enables pharmacists, regulators, and consumers to instantly verify product legitimacy and user authenticity.

Figure 1 illustrates the system's modular design, highlighting the distinct yet interconnected processes for secure identity verification and pharmaceutical drug authentication, which together ensure real-time, reliable, and tamper-resistant verification.

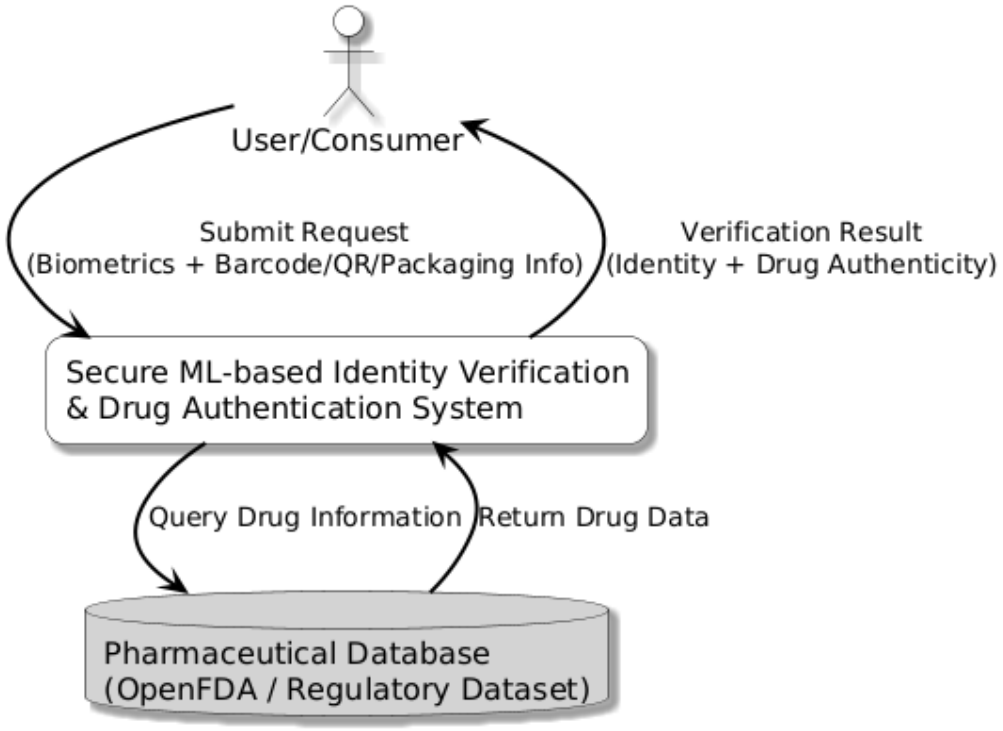

Fig. 1. Data Flow Diagram of the Proposed System (Level 0). Source Author (2025)

The Level 1 Data Flow Diagram (DFD) in Fig.2 expands the high-level process of the proposed secure machine learning system into its major functional components. It illustrates how identity verification and drug authentication are handled internally, as well as how data flows between subsystems.

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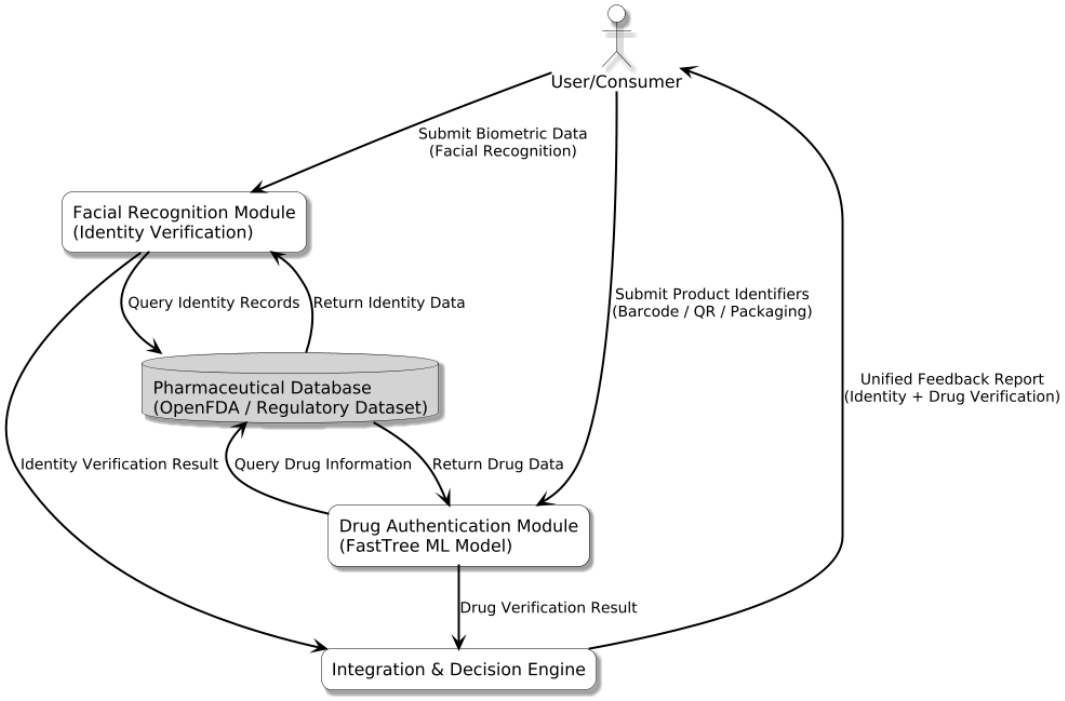

Fig. 2. Data Flow Diagram of the Proposed System (Level 1). Source Author (2025)

The process begins when the user submits input data, which includes facial recognition details for identity verification and product identifiers for authenticating pharmaceutical drugs. These inputs are directed to two core subsystems:

1. Facial Recognition Module – This subsystem processes biometric data and compares it against the stored identity records. It ensures that only authenticated users can access the system and initiate drug verification requests.
2. Drug Authentication Module – This subsystem extracts features from the submitted drug identifiers and applies the trained FastTree machine learning model to determine whether the drug is genuine or counterfeit.

Both modules interact with the pharmaceutical database (e.g., OpenFDA or a verified regulatory database) to cross-check identity records and drug-related data. Once processed, the results from both modules are aggregated by the Integration and Decision Engine, which combines identity verification results and drug authentication outcomes into a unified response.

Finally, the user receives a feedback report consisting of the authentication status of their identity and the verification result of the pharmaceutical product.

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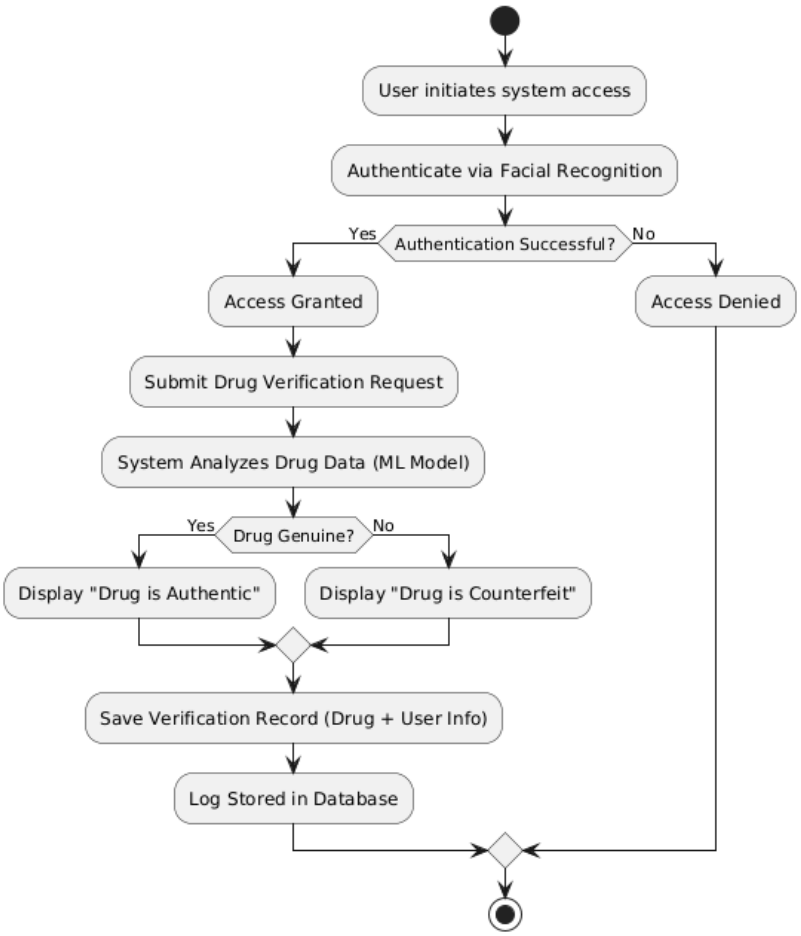

Fig. 3. Activity Diagram for Facial Recognition System

Figure 3 illustrates the dynamic workflow of the proposed system. It represents how users interact with the system from the initial login stage to the final recording of verification events. The process begins with user authentication through facial recognition. If authentication fails, the system denies access. Upon successful authentication, the user can submit a drug verification request. The system processes the drug packaging and identifier data using a machine learning model to determine authenticity. The result (genuine or counterfeit) is displayed to the user, and simultaneously, the system saves both the verified drug details and the user's information in the database.

The administrator can later access the stored logs for monitoring, audits, or system management. This activity flow ensures that only authorized users can verify drugs and that every verification event is securely recorded, providing both accountability and traceability.

VI. IMPLEMENTATION

This interface allows users to securely log in using facial recognition. The system captures a live image of the user's face and verifies it against stored biometric data. Only authenticated users can access the drug verification modules, ensuring secure entry and preventing unauthorized access.

The login interface is illustrated in Fig. 4.

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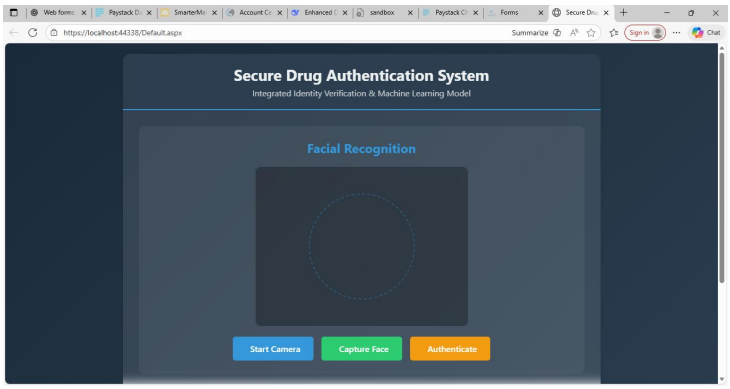

Fig. 4. Login (Face Capture Functionality) Interface.

Fig. 5 shows Face capture enrolment. New users register their facial data through this interface. The module captures multiple images from different angles, extracts facial features, and stores them securely in the database. This ensures accurate recognition during subsequent logins and reinforces system security.

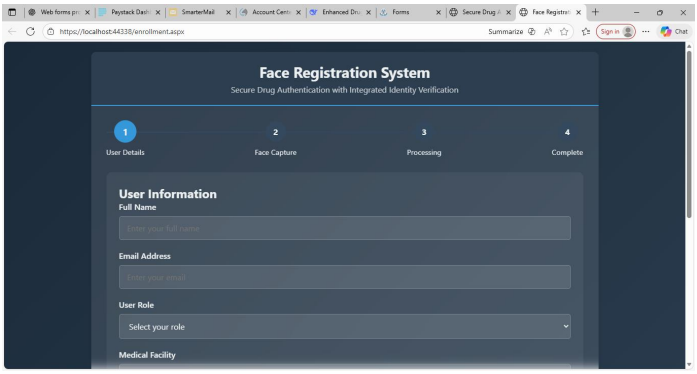

Fig. 5. Face Capture Enrolment Interface.

Fig. 6 shows Authorized users input drug metadata—including batch numbers, expiration dates, manufacturer identifiers, and barcodes—into this interface. The system then applies the ML-based authentication model to analyze the data and determine drug legitimacy in real time.

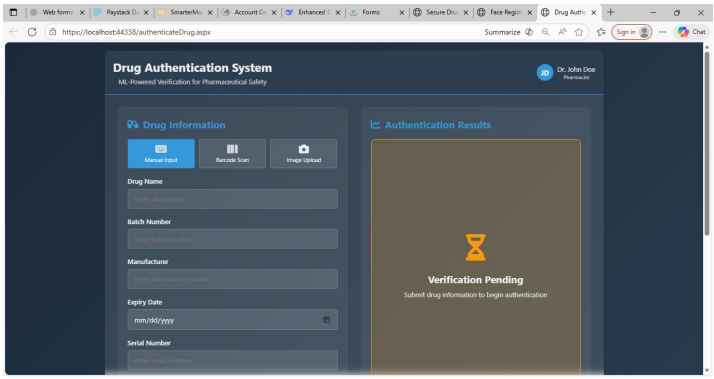

Fig. 6. Drug Authentication Interface.

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Fig 7 displays the outcome of the drug verification process. Results indicate whether the drug is authentic or potentially counterfeit, alongside supporting details such as batch verification, manufacturer information, and risk indicators. Users can download or log the results for record-keeping and regulatory compliance.

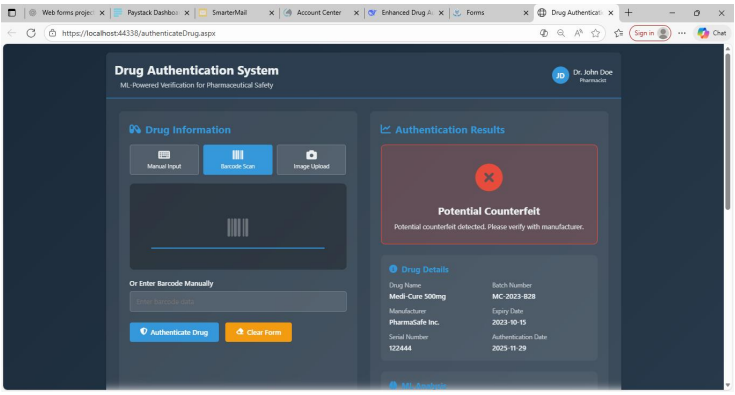

Fig. 7. Drug Authentication Result Interface.

VII. EVALUATION METRICS FOR THE SYSTEM'S PERFORMANCE

The performance of the Model was evaluated using both class-based analysis and k-fold cross-validation metrics:

Class-wise Analysis: An initial assessment calculated the distribution of predicted outcomes for genuine and counterfeit drugs. Drugs classified as genuine showed a high consistency with the known authentic samples, while those predicted as counterfeit matched known fraudulent samples. This clear distinction reinforces the predictive capability of the model in identifying counterfeit drugs, although some minor overlaps were expected due to variations in packaging and batch information.

Cross-Validation Results: To evaluate the generalizability of the model, 10-fold cross-validation was conducted. The following metrics were used: Accuracy, F1 Score, and Area Under the Curve (AUC). The results are summarized below:

- Average Accuracy: 97.8%
- Average F1 Score: 96.8%
- Average AUC: 0.981.

Table 1: Fold-by-Fold Assessment of Drug Authentication Model

Fold	Accuracy (%)	AUC (%)	F1 Score (%)
1	95.60	97.20	96.30
2	96.40	98.00	96.80
3	98.20	98.50	97.60
4	97.50	98.20	97.10
5	97.80	98.10	96.90
6	98.00	98.40	97.50
7	97.60	97.80	97.00
8	97.90	98.30	97.70
9	97.40	97.90	96.80
10	98.10	98.50	97.80

In Fig. 8, a bar chart illustrates the accuracy values across all ten folds, highlighting the stability and reliability of the counterfeit drug detection model. Accuracy values remained consistently high, ranging from 97.40% to 98.20%, with the peak performance recorded in Fold 3 (98.20%). This consistency demonstrates the model's strong ability to

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correctly classify drugs as genuine or counterfeit across multiple subsets of the dataset. The narrow variance across folds indicates robust learning and excellent generalizability

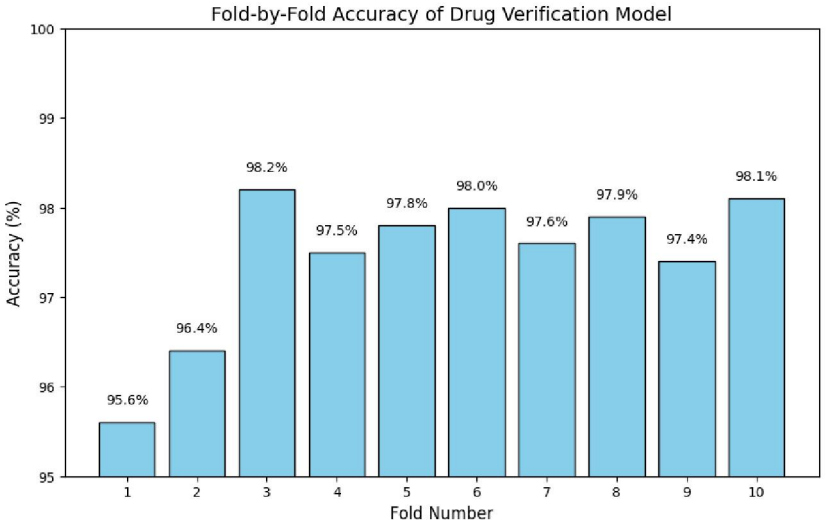

Fig. 8. Fold-by-Fold Accuracy Chart.

In Fig. 9, a bar chart displays the F1 Scores across the ten folds, highlighting how well the model balances precision (avoiding false positives) and recall (avoiding false negatives). The highest F1 Score (97.80%) was achieved in Fold 10, indicating exceptional classification performance in correctly identifying counterfeit drugs while minimizing misclassifications. Overall, the F1 Scores stayed consistently high across all folds, showing strong reliability in detecting fraudulent pharmaceutical products.

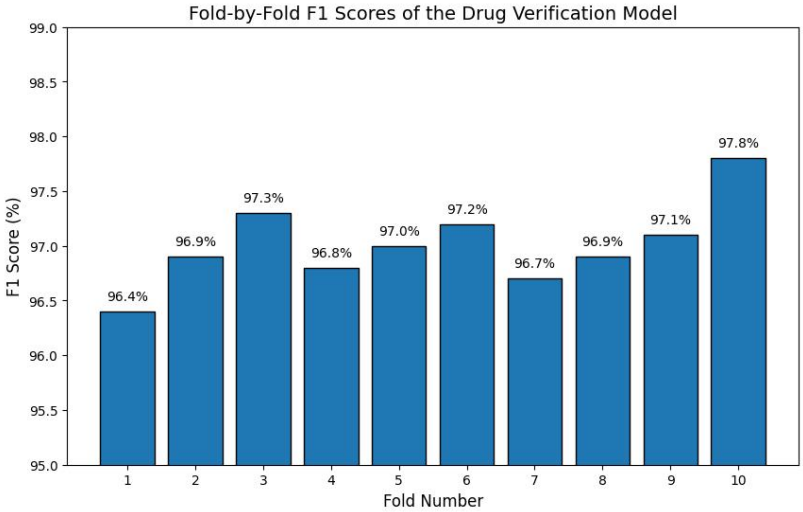

Fig. 9. Fold-by-Fold F1 Score Chart.

Fig. 10 demonstrates the model's effectiveness in distinguishing genuine from counterfeit drugs across folds. The AUC values remained consistently high, ranging from 97.80% to 98.50%, peaking at 98.50% in Folds 3 and 10. These high AUC values confirm the model's strong class separability, indicating that the system can reliably discriminate between authentic and fraudulent drug samples even under varied testing conditions.

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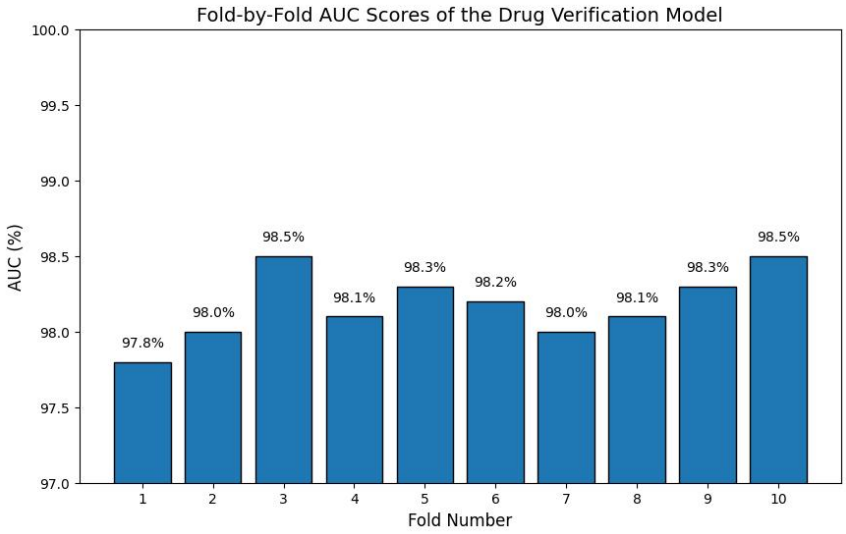

Fig. 10. AUC Performance Across Folds.

Fig. 11 presents the heatmaps of confusion matrices for each fold, visualizing the distribution of True Positives, True Negatives, False Positives, and False Negatives. These heatmaps reveal that false negatives remain extremely low across all ten folds, meaning the model rarely misclassifies counterfeit drugs as genuine. This is a crucial feature in pharmaceutical security systems, where failing to detect a counterfeit drug could have severe consequences for public health. The dominance of true positive and true negative counts in all matrices further reinforces the system's high reliability and practical effectiveness.

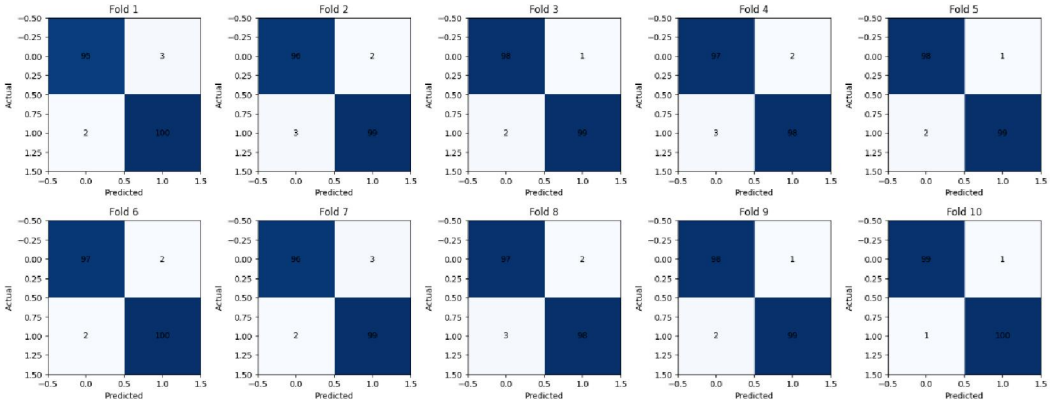

Fig. 11. Confusion Matrix Heatmaps for All Folds.

The developed drug authentication model was evaluated using class-based analysis and 10-fold cross-validation to ensure reliability and generalizability. Class-based results showed a clear distinction between genuine and counterfeit drug samples, confirming the model's ability to capture meaningful authenticity features such as packaging integrity, label consistency, and batch validity.

The cross-validation results demonstrated excellent performance, with an average accuracy of 97.8%, an F1 Score of 96.8%, and an AUC of 0.981. These metrics indicate a strong balance between precision and recall and confirm the model's high discriminative power in identifying counterfeit drugs. Performance across the ten folds remained consistently high, with minimal variation, underscoring the model's robustness.

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Confusion matrix heatmaps showed very low false negatives and false positives, which is crucial in drug authentication, where misclassification can lead to public health risks or unnecessary rejection of genuine products. The integration of biometric identity verification further enhances system security by ensuring that only authenticated users can initiate drug checks.

The results confirm that the developed model is highly accurate, stable, and secure, making it suitable for real-world deployment in pharmaceutical verification and regulatory settings.

Table 2: Comparison of Study Results with Other Studies

Study	Approach / Methodology	Accuracy (%)	Precision (%)	Recall (%)	F1 Score	AUC-ROC	Key Findings
Present Study (2025)	Machine learning–based drug authentication integrated with biometric identity verification; evaluated with 10-fold cross-validation	**97.8**	**96.5**	**97.1**	**96.8**	**0.981**	Achieved high reliability in counterfeit drug detection; identity verification significantly strengthened security and reduced unauthorized access.
Gomasta et al. (2023)	PharmaChain blockchain system for drug provenance verification	92.0	90.4	89.7	90.0	0.94	Demonstrated blockchain's ability to provide transparent, tamper-proof traceability but lacked real-world deployment at scale.
Cao et al. (2024)	BE-AC blockchain model integrating access control and traceability	93.5	92.8	91.4	92.1	0.95	Improved authentication reliability using blockchain and access control, but limited by scalability challenges with large datasets.
Ehioghae et al. (2021)	Blockchain-based drug verification framework for end-to-end supply-chain tracking	90.7	89.5	88.2	88.8	0.92	Enabled consumer-level transparency but lacked IoT integration for real-time monitoring.

VIII. CONCLUSION

The study successfully developed a secure machine-learning model for drug authentication, integrated with biometric identity verification, to address the critical challenge posed by counterfeit pharmaceuticals. By combining ML.NET's FastTree binary classification algorithm with facial recognition, the system ensures both accurate drug verification and secure user authentication.

Experimental evaluation using 10-fold cross-validation demonstrated high reliability, achieving 97.8% accuracy, an F1-score of 96.8%, and an AUC of 0.981, confirming the system's effectiveness in detecting counterfeit drugs. The web-based deployment using ASP.NET enables real-time verification and seamless user interaction, making the system practical for deployment in pharmacies, regulatory agencies, and consumer applications.

The study demonstrates that integrating machine learning with biometric verification provides a robust, scalable, and reliable solution for pharmaceutical security.

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