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A Secure and Scalable Online Auction System Leveraging Hybrid Machine Learning Models and Rule-Based Systems for Real-Time Fraud Detection and Transparent Bidding

S. Harsshita[1], A. Shruthi[2], B. Kanaka Srinidhi[3], Ms. Jayalakshmi[4]
[1,2,3]UG Scholar, Dept. of CSE-BDA, SRM Institute of Science & Technology, Ramapuram, Chennai, India.
[4]Assistant Professor, Dept. of CSE-BDA, SRM Institute of Science & Technology, Chennai, India.
Email ID: *sv6285@srmist.edu.in[1], as3103@srmist.edu.in[2], br3561@srmist.edu.in[3], jayalakp@srmist.edu.in[4]*

Abstract
The Web-Based Online Auction Platform is an innovative e-commerce solution designed to facilitate secure and dynamic transactions between buyers and sellers. Supporting multiple auction formats, including Silent Auction, Buy-It-Now, and Standard Auction, the platform ensures flexibility and engagement for users. Real-time bidding updates are seamlessly integrated using Firebase, enhancing interaction and responsiveness. To strengthen security and trust, the system incorporates advanced Machine Learning (ML) and Deep Learning (DL) models, such as Random Forest, Isolation Forest, and Autoencoders, for fraud detection. These models analyze bidding behaviors, identify anomalies, and mitigate risks associated with fraudulent activities. For transaction security, the platform leverages Razor pay-powered escrow payments, ensuring that funds are securely held until both parties confirm the transaction, thereby minimizing disputes and enhancing user confidence. The platform is designed with a modular architecture, ensuring scalability and efficient handling of large user bases. This research highlights the system's capability to offer a secure, interactive, and user-centric online auction experience with robust fraud detection mechanisms and transaction security features, making it an ideal solution for organizations and individuals seeking a reliable digital auction environment.
Keywords: *Auto encoders, Buy-It-Now, Escrow Payments, Fraud Detection, Isolation Forest, Online Auction, Random Forest, Real-Time Bidding, Silent Auction, Standard Auction.*

1. Introduction
Auctions have been a widely used mechanism for buying and selling goods for centuries, allowing competitive bidding to determine fair market prices. Traditionally, auctions were conducted in physical locations, requiring participants to be present at a designated venue. However, with the advancement of digital technologies, online auction systems have emerged as a more efficient and accessible alternative. Digital auction platforms enable buyers and sellers to participate in bidding from anywhere in the world, eliminating geographical constraints and expanding market opportunities. These platforms facilitate a range of auction formats, including Standard Auctions, Silent Auctions, and Buy-It-Now options, catering to different user preferences. Despite their advantages, digital auction systems face several challenges, particularly in terms of security, fraud prevention, and transaction transparency. Fraudulent bidding behaviors, such as shill bidding, bid shielding, and account takeovers, pose significant risks to both buyers and sellers. Such activities distort market prices, reduce trust in the system, and create unfair competition. Additionally, ensuring secure financial transactions is a critical concern, as online platforms are vulnerable to payment fraud, chargeback disputes, and unauthorized transactions. Without robust fraud detection mechanisms, digital auctions can become susceptible to exploitation, leading to financial losses and user dissatisfaction. To address these challenges, our Web- Based Online Auction Platform integrates advanced fraud detection models based on Machine Learning (ML) and Deep Learning (DL). The system employs Random Forest, Isolation Forest, and Autoencoders to analyze bidding behavior, detect anomalies, and mitigate fraudulent activities in real

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time. By leveraging these techniques, the platform enhances security and trust, ensuring a fair bidding environment for users. Furthermore, the platform implements real-time bidding updates using Firebase, allowing seamless interaction between participants. Transaction security is reinforced through Razorpay-powered escrow payments, ensuring that funds are securely held until both parties confirm the completion of a transaction. This minimizes disputes and enhances financial security for buyers and sellers. Built on a modular and scalable architecture, the system is designed to accommodate a growing user base while maintaining performance and reliability. By combining advanced fraud detection, secure payment processing, and a user- friendly interface, the proposed platform offers a comprehensive solution for organizations and individuals seeking a secure and transparent online auction experience. This research aims to highlight the importance of integrating fraud detection and transaction security measures in digital auction systems while demonstrating the effectiveness of the implemented solutions in ensuring a safe and efficient marketplace.

2. Literature Review

Early research on online auction security explored privacy-preserving mechanisms in big data environments. One study proposed a method that enhanced scalability, efficiency, and truthfulness while ensuring secure transactions with minimal computational overhead [1]. As cloud computing and IoT applications grew, another study introduced an auction-based algorithm for cloud resource allocation, optimizing service profitability and performance [2]. Further advancements in cloud auctions led to a deadline-aware multi-resource allocation mechanism, ensuring efficient and fair resource distribution in cloud-hosted platforms [3]. With the increasing reliance on online marketplaces, fraud detection became a major area of focus. One study developed a real-time fraud detection framework using Support Vector Machines (SVM), achieving high precision and reducing errors in e-market transactions [4]. Expanding on this, researchers proposed a fusion model combining SVM, Artificial Neural Networks (ANN), and fuzzy logic, which significantly improved accuracy in detecting fraudulent activities, particularly in shill bidding [5]. To enhance adaptability, another study introduced an incremental learning framework for fraud detection, allowing the system to continuously update classifiers using real auction data [6]. Shill bidding, a persistent problem in online auctions, has been widely studied. A decision tree-based approach was introduced to detect shill bidding in real- time, effectively blocking fraudulent users before they could influence auction outcomes [7]. Another study further improved the collusive shill bidding detection algorithm (CSBD), making it more efficient, though challenges remained in validating results due to the lack of labeled fraud data [8]. Advancements in online auction mechanisms also included blockchain and deep learning applications. A comprehensive survey examined blockchain's potential in auction systems, focusing on decentralization, transparency, and challenges in widespread adoption [9]. Meanwhile, deep learning techniques were applied to auction mechanism design, analyzing how AI-driven architectures adapt to dynamic bidding environments and improve system efficiency [10]. Real-time auction forecasting has also gained attention. A study introduced a real- time auction price prediction model using Z-scores, K-Fold cross-validation, and RMSE, enabling accurate forecasting based on historical bidding data [11]. Another research effort developed a lift-based bidding system, which optimized revenue and improved auction performance in Real- Time Bidding (RTB) environments [12]. More recently, AI-driven auction platforms have emerged as a solution for improving both security and user experience. One study proposed an AI-powered online auction platform, integrating fraud detection mechanisms and seamless transaction handling [13]. Another research effort introduced a robust auction platform with enhanced security measures, focusing on fraud prevention techniques and secure payment processing [14]. The latest advancements include a study on AI- enhanced collusive shill bidding detection, which improves fraud

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identification in commercial online auctions by analyzing coordinated bidding behaviors.

3. Existing System

The existing system for online auctions faces several significant limitations that hinder its overall effectiveness. A primary challenge is the absence of robust fraud detection mechanisms, making it difficult to identify fraudulent activities such as bot bidding, bidder collusion, and false bids in real time. Many platforms rely on manual monitoring or basic rule-based systems, which are prone to human error and struggle to handle large volumes of data. Additionally, payment systems on some auction platforms remain vulnerable to fraud, including payment disputes and chargebacks, as they often lack secure transaction handling mechanisms such as escrow, which ensures that funds are released only when both parties fulfill their obligations. Another major concern is the limited transparency of the auction process, as users are often uncertain about the authenticity of bids due to the lack of visibility in the bidding process. Furthermore, many auction platforms offer only a single auction format, failing to accommodate diverse user preferences. The user experience is also frequently compromised due to inefficient navigation, delays in bid updates, and occasional downtimes during high-traffic periods. These limitations collectively impact the reliability, fairness, and security of existing online auction platforms, leading to diminished user confidence and engagement.

4. Proposed System

The proposed online auction system aims to address the limitations of the existing system by integrating advanced fraud detection mechanisms, secure payments, and an enhanced user experience. The platform will incorporate Machine Learning-based fraud detection using Isolation Forest and Autoencoder models to analyze bidding patterns and detect fraudulent activities such as bot bidding, collusion, and abnormal bid sequences in real time. This proactive approach will significantly reduce the risk of fraudulent transactions. To enhance payment security, the system will integrate Razorpay with escrow functionality, ensuring that funds are held securely until the transaction is successfully completed. This prevents disputes and chargebacks while improving trust between buyers and sellers. The auction system will support multiple auction formats to cater to different user preferences, providing flexibility beyond traditional bidding mechanisms. A real- time, scalable architecture will be implemented to ensure seamless bid updates, reduce latency, and maintain high system availability even during peak auction periods. Moreover, the platform will feature an intuitive user interface, improving accessibility and navigation for participants. By integrating fraud detection, secure payments, enhanced transparency, and an improved user experience, the proposed system aims to create a reliable, efficient, and secure online auction platform that fosters trust and fairness among participants. (Figure 1)

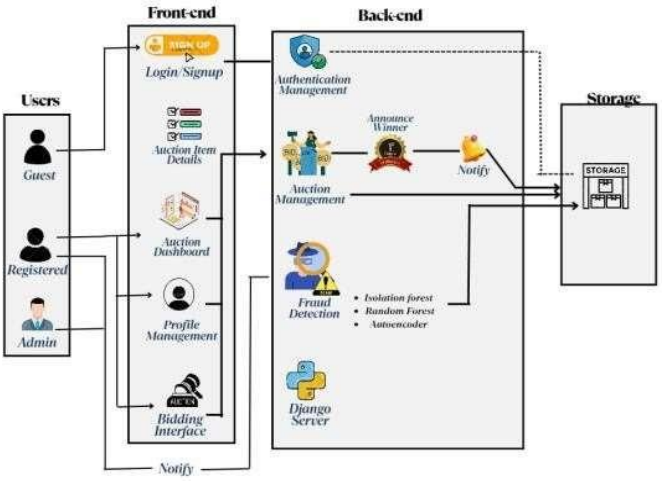

Figure 1 Architecture Diagram

5. Methodology

The development of the online auction system with fraud detection follows a structured methodology, ensuring seamless integration of frontend, backend, and machine learning models. The system aims to provide a secure and transparent auction environment, preventing fraudulent activities while enabling fair bidding.

5.1. System Design

Backend Framework and Technologies: The backend of the online auction system is built using Django, a high-level Python web framework known

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for its scalability and robustness. Django's modular architecture allows for efficient management of user authentication, auction listings, and bidding logic. Additionally, Web Sockets are integrated to enable real-time communication between the frontend and backend, ensuring seamless bid updates and instant notifications for users. The system also leverages Razorpay for secure payment processing, with an escrow system to hold funds until both parties confirm the transaction.

5.2. Database Design and Management

The system uses a relational database to store and manage data, including user profiles, auction listings, bids, and transaction records. Key tables include Users, which stores user details such as name, email, role (buyer, seller, admin), and authentication credentials; Auctions, which contains auction details such as product name, description, starting price, auction type, and duration; Bids, which records bid amounts, timestamps, and bidder information for each auction; and Transactions, which tracks payment details, including escrow status and transaction confirmations. The database is designed to ensure data integrity, with constraints and relationships (e.g., one-to-many relationships between users and bids) enforced at the schema level.

5.3. Real-Time Functionality

Web Sockets are used to enable real-time communication between the frontend and backend. When a user places a bid, the backend immediately broadcasts the updated bid amount to all participants in the auction. This ensures that all users receive real-time updates without needing to refresh the page. Web Sockets also handle notifications, such as auction closures and payment confirmations, enhancing the user experience. Payment Gateway Integration: The system integrates Razor pay, a secure payment gateway, to handle financial transactions. Razor pay's escrow functionality ensures that funds are held securely until both the buyer and seller confirm the transaction. This minimizes disputes and chargebacks, enhancing trust between participants. The payment process is automated, with notifications sent to both parties upon successful transaction completion.

5.4. User Authentication and Role Management

User authentication is managed using Django's built-in authentication system, which supports secure password storage, session management, and account verification. Users can register as buyers, sellers, or administrators, with each role having distinct permissions and access levels. The system also supports email verification to ensure the authenticity of user accounts. To manage user permissions, the system implements role-based access control (RBAC). Buyers can browse auctions, place bids, and track bidding history; sellers can create and manage auction listings, monitor bids, and close auctions; and administrators oversee system operations, verify seller authenticity, and monitor auction activities. RBAC ensures that users can only access functionalities relevant to their role, enhancing system security

5.5. Auction Management and Bidding Logic

The auction management system is designed to provide flexibility and fairness, supporting multiple auction formats to cater to diverse user preferences. Sellers can create auction listings by specifying product details, auction type, starting price, and duration. The system supports three primary auction types

5.6. Standard Auction

In this format, buyers compete by placing increasingly higher bids. The highest bid at the auction close determines the winner. This format encourages competitive bidding and is ideal for high-demand items.

5.7. Silent Auction

Bidders submit private bids, and the highest bidder wins. This format is often used for charity events or exclusive items, as it allows bidders to participate discreetly without revealing their bids to others. Buy-It-Now Auction: This format allows users to purchase items instantly at a fixed price, bypassing the bidding process. It is ideal for sellers who want to sell items quickly and for buyers who prefer immediate transactions. The system validates auction parameters to ensure compliance with platform guidelines, such as minimum starting prices, maximum auction durations, and appropriate

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product descriptions. Once validated, the auction is published and made available to buyers. Buyers can place bids on active auctions, with the system validating each bid to ensure it meets the minimum bid increment and is placed within the auction duration. The backend processes bids in real time, updating the auction status and notifying all participants via Web Sockets. This real- time functionality ensures that all users are aware of the latest bid amounts and auction status, creating a dynamic and engaging bidding environment. Sellers and administrators can monitor active auctions, view live bids, and track bidder activity. Detailed analytics, such as bid history and bidder participation rates, are provided to help sellers make informed decisions. Once the auction duration expires, the system automatically closes the auction and declares the highest bidder as the winner. The user workflow of auction mechanism is shown in (Figure 2)

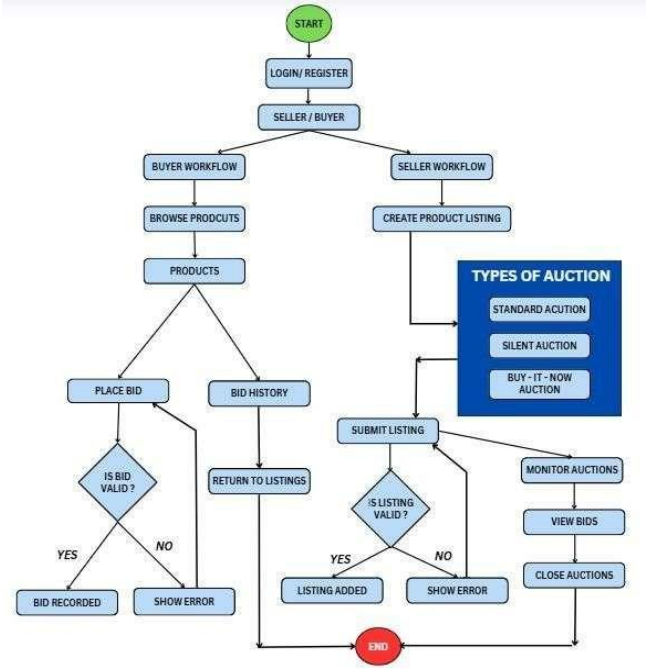

Figure 2 User Engagement of Online Auction

6. Fraud Detection Integration

6.1. Rule-Based Fraud Detection

The system implements a rule-based fraud detection mechanism to identify suspicious activities such as bid sniping, duplicate accounts, and rapid bidding. Rules include detecting bids placed in the last few seconds of an auction, flagging multiple accounts using the same IP address or device and identifying sellers with poor ratings or repeated listing cancellations. These rules are enforced in real time, ensuring immediate detection and prevention of fraudulent activities.

6.2. Machine Learning Model Integration

This project employs a hybrid model combining Isolation Forest, Auto encoders, and a Random Forest meta- classifier to detect fraudulent activities in online auctions. The system is designed to identify various types of fraud, including shill bidding (fake bids to drive up prices), collusion (bidders working together to manipulate prices), seller fraud (sellers cancelling auctions unfairly), and payment fraud. This is detected by finding the patterns between the features as shown in Figure 3 The dataset contains 5,000 records with 16 features, including bidding ratios, auction duration, bid intervals, timestamps, and whether the seller cancelled the auction. Before training, the data underwent pre- processing: missing values were handled, categorical features were encoded, and additional features such as the hour of the day, day of the week, average bid interval, and cancellation ratio were created through feature engineering. The data was then scaled using Standard Scalers to ensure all features were on the same level. (Figure 3)

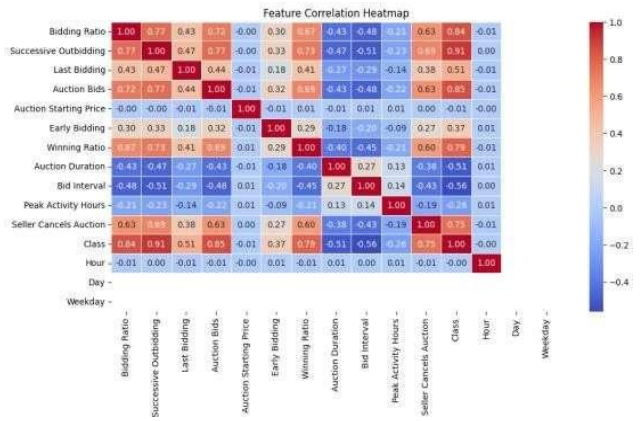

Figure 3 Feature Correlation

The Isolation Forest is an unsupervised anomaly detection algorithm that identifies outliers by randomly selecting features and splitting values to

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isolate data points that deviate from normal patterns. It is particularly effective for detecting clear deviations in behavior, such as unusually high bids or rapid bidding, making it ideal for identifying shill bidding and collusion. On the other hand, the Auto encoder is a neural network designed to reconstruct normal behaviour. It consists of an encoder that compresses input data into a lower- dimensional representation and a decoder that reconstructs the original data. By comparing the reconstructed data to the original, the Auto encoder can flag anomalies based on high reconstruction errors, making it effective for detecting subtle, complex fraud patterns like seller fraud and payment fraud. While the Isolation Forest excels at detecting clear outliers, the Auto encoders is better suited for identifying nuanced anomalies. To leverage the strengths of both models, their predictions are combined as features and fed into a Random Forest meta-classifier. This hybrid approach improves overall accuracy and robustness, ensuring comprehensive fraud detection while minimizing false alarms. The Isolation Forest (n_estimators=100, contamination=0.15) identifies outliers by isolating data points that deviate from normal patterns, while the Auto encoder flags anomalies based on a reconstruction error threshold of 45 and the Table 1 shows the Auto encoders architecture. In this project, precision, recall, ROC-AUC, and accuracy are used as key evaluation metrics to assess the fraud detection model's effectiveness. Precision measures how many of the predicted fraudulent cases are actually fraudulent, ensuring minimal false positives. Recall indicates how well the model captures actual fraud cases, minimizing false negatives. ROC-AUC (Receiver Operating Characteristic - Area Under Curve) evaluates the model's ability to distinguish between fraudulent and non- fraudulent transactions, with higher values indicating better classification performance. Accuracy provides an overall measure of correct classifications but may be less reliable in imbalanced datasets. By using these metrics together, the model ensures a balanced trade-off between detecting fraud and minimizing false alarms, improving real- world applicability.

7. Result

The online auction system successfully achieved its objectives, delivering a secure, scalable, and user-friendly platform for buyers and sellers. The integration of Web Sockets enabled real-time bid updates and notifications, ensuring a responsive and interactive user experience. The backend, built using Django, efficiently managed user authentication, auction listings, and bidding logic, while Razor pay provided secure payment processing through an escrow system, minimizing disputes and enhancing trust. The hybrid fraud detection system, integrating Isolation Forest, Auto encoders, and a Random Forest meta-classifier, demonstrated strong performance in identifying fraudulent transactions. Individually, the Isolation Forest achieved a precision of 0.78 and recall of 0.85, while the Autoencoder achieved a precision of 0.80 and recall of 0.88. By combining both models' predictions as features and feeding them into a Random Forest meta-classifier (n_estimators=100, max_depth=10), the hybrid approach significantly improved performance, achieving a precision of 0.84, recall of 0.93, and an overall accuracy of 96%, with a ROC-AUC score of 0.948. The confusion matrix highlights the model's classification performance, showing minimal misclassifications, indicating that fraudulent cases are well detected with a high recall. The ROC curve (F demonstrates a strong separation between positive (fraudulent) and negative (non- fraudulent) classes, with an AUC of 0.948, confirming the model's robustness. The Precision-Recall (PR) curve with AUC = 0.924 further emphasizes the model's effectiveness, showing a gradual decline in precision as recall increases. The sharp drop at high recall values suggests that capturing more fraudulent cases leads to some misclassifications. Overall, the hybrid approach enhances fraud detection by leveraging the Isolation Forest's strength in identifying clear outliers and the Autoencoder's sensitivity to subtle anomalies, while the meta-classifier refines the final decision. This method ensures a balanced trade-off between precision and recall, effectively minimizing false positives while maintaining a high detection rate for fraudulent activities as shown in (Figure 4)

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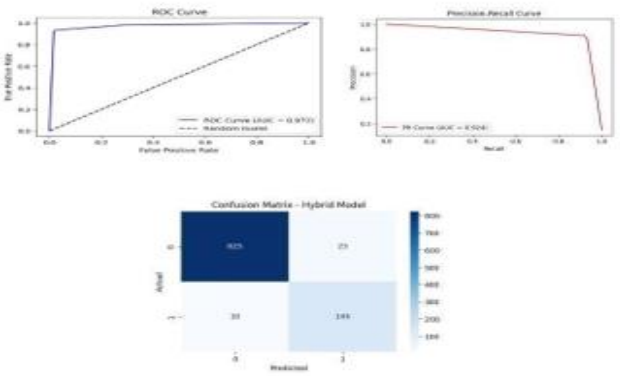

Figure 4 Evaluation Metrics for Hybrid Model

Table1 Auto Encoder Architecture

Layer(type)	Output shape	Param#
nput_layer_2 (InputLayer)	(None, 27)	0
dense_6(Dense)	(None, 128)	3,584
dense_7 (Dense)	(None, 64)	8,256
dense_8 (Dense)	(None, 32)	2,080
dense_9 (Dense)	(None, 13)	429
dense_10 (Dense)	(None, 32)	448
Dense_11(Dense)	(None, 64)	2,112
Dense_12(Dense)	(None, 128)	8,320
Dense_13(Dense)	(None, 27)	3,483
Total params Trainable params Non-trainable params	28,712 (112.16 KB) 28,712 (112.16 KB) 0 (0.00 B)	

Overall, the project delivered a robust and scalable online auction platform, combining real-time functionality, secure payment processing, and advanced fraud detection. The system's modular architecture and hybrid approach to fraud detection ensured high performance, reliability, and user trust, meeting all project objectives.

Conclusion

This project represents a significant step forward in creating a secure, transparent, and efficient online auction platform. The hybrid fraud detection system, combining advanced machine learning techniques, has proven highly effective in identifying and mitigating fraudulent activities, ensuring a fair and trustworthy bidding environment. Real-time updates and secure payment processing further enhance the user experience, fostering confidence among buyers and sellers. The system's scalability and robust performance make it a reliable solution for organizations and individuals seeking a modern, secure, and user-friendly auction platform. Overall, this project successfully delivers a comprehensive solution that addresses the key challenges of online auctions, setting a new standard for security and usability in the digital marketplace. Future enhancements could integrate block chain technology for greater transparency and decentralization, further reducing fraud risk.

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