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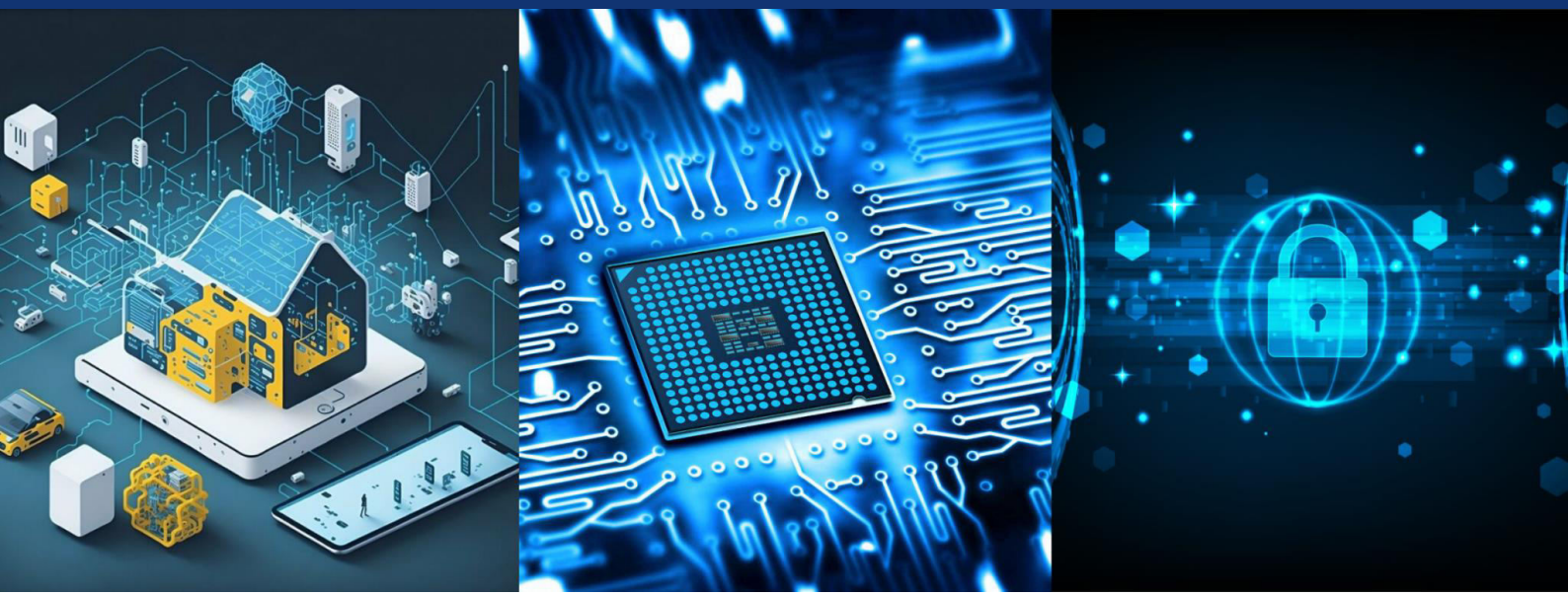

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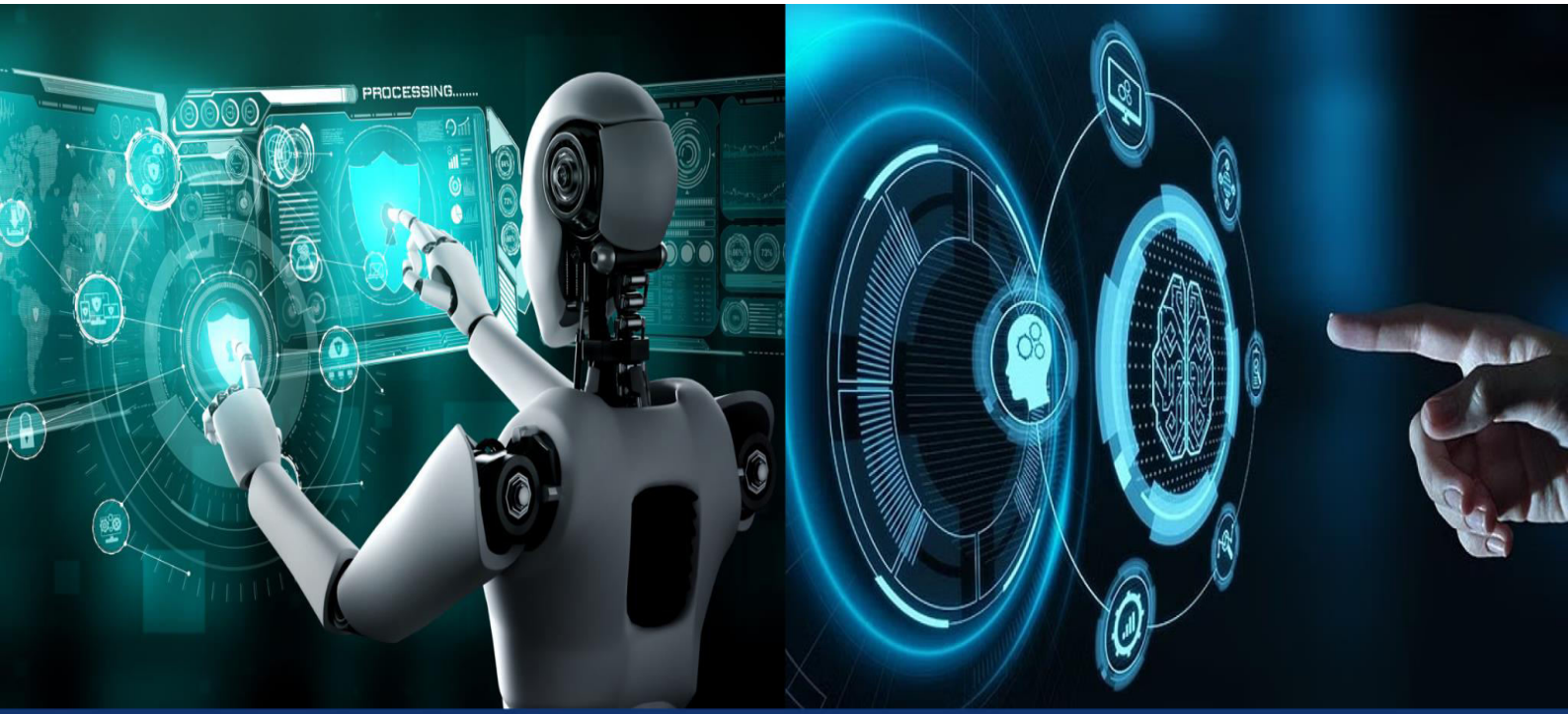

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Blockchain-Enabled Escrow System for Transparent Online Transactions

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ABSTRACT Trust issues and fraudulent practices often arise in the dealings of anonymous participants in online payments, requiring the need for an intermediary in the form of a bank or other business platforms for acting as escrow services. The traditional approach is faced with numerous drawbacks, ranging from expensive transaction costs, lack of transparency regarding decision making, inefficient dispute resolution process, to centralized control over freezing or reversing any transactions. Trust-based systems lacking automated conditional enforcement mechanisms are inherently flawed. This paper discusses a completely decentralized escrow service based on the use of blockchain technologies that creates a secure, trustworthy, and automated environment for executing transactions within a digital market. Designed based on the Ethereum blockchain platform with the use of Solidity smart contracts, the offered solution allows one to securely lock buyer money and enforce time-lock mechanisms related to product delivery. Among other features, this design implements role-based management using cryptographic wallets, a reputation system that helps to prevent malicious actors from participating in transactions, and a decentralized oracle component for resolving disputes objectively. This blockchain solution is interfaced with a dApp built in React.js, which guarantees secure transaction records without any intermediary fees.

KEYWORDS: Blockchain Technology, Decentralized Escrow, Smart Contracts, Ethereum, Trustless Transactions, Decentralized Application (dApp), Time-Locked Escrow

I. INTRODUCTION

Rapid development of e-commerce has allowed smooth transactions on a global level; nonetheless, online transfers between strangers are prone to many problems concerning low levels of trust and potential fraud. As a rule, in order to avoid such problems and ensure safety of the transaction, users have to depend on third parties, such as commercial banks or corporations, which run their own trading platforms (e.g., Amazon, PayPal, and Upwork). Such approaches are associated with obvious drawbacks connected with the nature of the system. First, these structures do not allow much transparency, charge high commissions for services of protecting customers' rights, and possess the right to postpone, change, or reverse payments made. Second, due to the closed nature of the system, no one can see the rules according to which these decisions are made. Moreover, conventional escrow systems depend purely on trust within institutions and not cryptography. The need for human intervention in resolving disputes results in inherent delays and increased levels of frustration for users. Moreover, such conventional escrow systems lack automation, particularly the automation of releasing funds that have been locked depending on time or conditions. These escrow systems do not use any decentralized reputational or fraud prevention measures, thus enabling the same people to get back into the system again. To overcome these structural weaknesses, Blockchain has developed an extremely secure and decentralized platform wherein transactions can be safely automated using smart contracts. The entire verification process is decentralized, which guarantees secure and automatic management of funds without any involvement of a third party. The goal of this project is to create a reliable escrow system based on blockchain technology that will be used for conducting buyer-seller transactions with maximum efficiency and transparency. In the suggested design, smart contracts based on the Ethereum platform are used for auto-locking buyer payment and strictly imposing time constraints on deliveries. With the help of computer algorithms, the project will ensure that money is paid out only after delivery notification.

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II. RELATED WORK

Recent literature highlights the significance of incorporating blockchain technology into digital transactions, though key vulnerabilities exist regarding gas optimization, user accountability, and scalability. Sandadi et al. proposed a decentralized escrow mechanism using Ethereum smart contracts to ensure secure, peer-to-peer payments without third-party intermediaries. However, this protocol struggles with scalability during network congestion and relies heavily on oracle services for complex, subjective disputes. Similarly, Zhang, Lee, and Gupta applied formal verification methods to secure escrow smart contracts against critical software flaws like reentrancy attacks. While effective for managing financial assets, their approach requires substantial off-chain computational resources and relies solely on static code analysis, ignoring the dynamic nature of blockchain systems. Furthermore, Matzutt, Jensen, and Henze introduced "SmartJudge" to handle dispute resolution in two-party protocols via third-party judges; unfortunately, utilizing decentralized judges can introduce potential resolution delays and corruption risks.

Currently, traditional centralized e-commerce systems continue to suffer from high transaction fees, lack of transparency, manual processing delays, and dependency on single points of failure. To address these gaps, the proposed **Blockchain-Enabled Escrow System** leverages Ethereum smart contracts to fully automate fund handling and transaction execution. This proposed system builds upon these foundational concepts by introducing secure payment locking, automated conditional settlements, a refined oracle-based dispute resolution mechanism, and an immutable on-chain seller reputation system. By doing so, it effectively eliminates the need for centralized intermediaries while building trust and transparency between transacting parties.

III. PROPOSED ALGORITHM

The proposed system employs a comprehensive, multi-tiered blockchain architecture designed to facilitate secure and trustless e-commerce transactions. As illustrated in the system diagram, the architecture is divided into distinct, interacting layers that seamlessly bridge the user experience with the underlying blockchain network.

Layer 1: Client & Presentation Layer
At the top level of the architecture, the Client and Presentation Layer allows users—acting as either Buyers or Sellers—to access the platform securely using MetaMask Wallets. This integration ensures non-custodial authentication and transaction signing directly from the user's local device. The user interface itself is powered by a React.js Web Application that features dedicated, role-specific views. These interfaces include a Buyer Dashboard for initiating purchases and confirming deliveries, a Seller Dashboard for listing products and managing inventory, and a Dispute Panel dedicated to raising and tracking transaction conflicts.

Layer 2: Blockchain Interaction Layer
To connect the traditional web frontend with the decentralized ledger, the Blockchain Interaction Layer serves as the critical communication bridge. This layer utilizes the MetaMask Provider alongside the Web3.js and Ethers.js libraries. This middleware acts as a translation engine, taking user actions from the React application, formatting them into secure transaction payloads, and relaying them directly to the blockchain network for processing.

Layer 3: Escrow Smart Contract Layer
The core business logic of the marketplace is governed by the Escrow Smart Contract, which is programmed in Solidity. This autonomous contract encompasses several critical sub-modules to manage the lifecycle of a transaction. It handles Role and Product Management by registering verified users and cataloging active marketplace listings. Furthermore, it executes Escrow and Fund Locking to securely hold buyer funds (ETH) in a trustless vault, enforces Order Management and Time-Lock Auto Releases for temporal delivery deadlines, and oversees Reputation Management to immutably track the success rate of the transacting parties.

Layer 4: Oracle Layer (Integrated Component)
Operating in parallel with the main interaction flow is an integrated Oracle Service. This component acts as a bridge between off-chain, real-world data and the on-chain smart contracts to aid in complex dispute resolutions. Its primary responsibilities include verifying delivery statuses, validating buyer-seller identities, and confirming external events to ensure fair and accurate arbitration when conflicts arise.

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Layer 5: The Distributed Ledger

The foundational layer of the entire system is the Ethereum Blockchain, specifically utilizing the Sepolia Testnet environment. This distributed ledger acts as the ultimate, immutable source of truth where all smart contract states, locked escrow balances, and transaction histories are permanently and securely recorded.

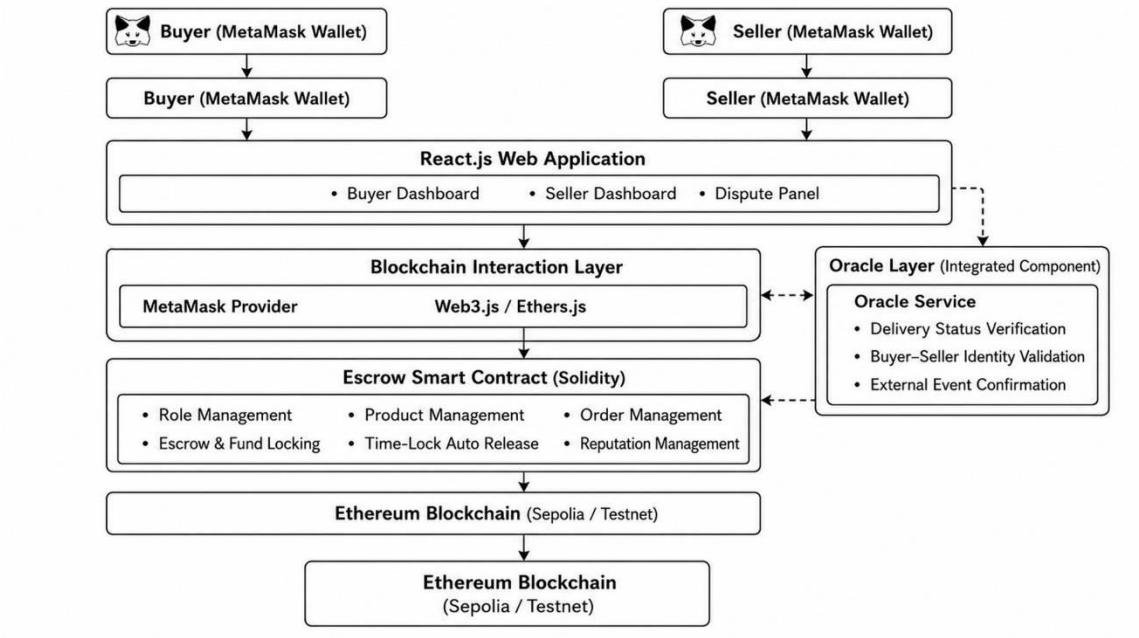

Figure 1: Architecture of Escrow System

IV. IMPLEMENTATION

The newly designed decentralized escrow system was successfully developed and deployed using leading Web3 technologies, specifically targeting the Ethereum Sepolia Test Network. To ensure a consolidated and secure environment, the fundamental market structure—including role-based access control and digital asset cataloging—was programmed within a unified Solidity (^0.8.20) smart contract. The entire development process, encompassing the compiling, testing, and deployment of the escrow logic, was conducted using the Hardhat framework to guarantee stability before interacting with the live testnet.

At the heart of the system is the Escrow Fund Locking Engine. When a buyer initiates a purchase, their Ethereum (ETH) is securely locked within the smart contract's vault, and a strict temporal delivery deadline is mathematically enforced using the blockchain's timestamp. The protocol enables deterministic, trustless settlements via atomic transfers. Buyers can finalize the transaction to release funds upon successful delivery, or sellers can claim the funds once the predefined timeout expires. To handle exceptions, an oracle-driven dispute resolution module allows buyers to freeze funds if an issue arises. An authorized Oracle Administrator can then review the dispute and execute a final verdict, securely routing the locked ETH as either a refund to the buyer or a payout to the seller. Furthermore, all successful settlements automatically and immutably adjust the seller's on-chain reputation score.

The Presentation Layer of the platform was built as a dynamic Single Page Application (SPA) using React.js. It features distinct, real-time dashboards tailored for buyers, sellers, and oracle administrators. To bridge the gap between the traditional web browser and the decentralized ledger, the application utilizes the Ethers.js library as middleware to format JSON-RPC requests. User authentication and cryptographic transaction signing are managed entirely through the MetaMask browser extension, empowering users to maintain full, non-custodial control over their private keys. To optimize the user experience, asynchronous execution wrappers were implemented to mask network confirmation latencies, ensuring that the interface updates dynamically as EVM event logs are verified on-chain.

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V. SIMULATION RESULTS

The implemented Blockchain-Based Decentralized Escrow Marketplace successfully demonstrates a secure and trustless digital commerce ecosystem on the Ethereum Sepolia Test Network. Simulation outcomes confirm that role-based registration securely authenticates users via MetaMask, allowing sellers to list inventory and buyers to purchase items by locking ETH directly within the smart contract. Etherscan block explorer logs validate that these funds are held securely without any centralized intermediaries. In the event of a conflict, the oracle-driven dispute mechanism successfully freezes the transaction, enabling authorized administrators to arbitrate and route funds fairly. Finally, atomic settlements automatically transfer Ethereum and update immutable seller reputation scores upon completion, proving that the system ensures total financial transparency and tamper-proof data consistency despite minor blockchain-induced transaction latency..

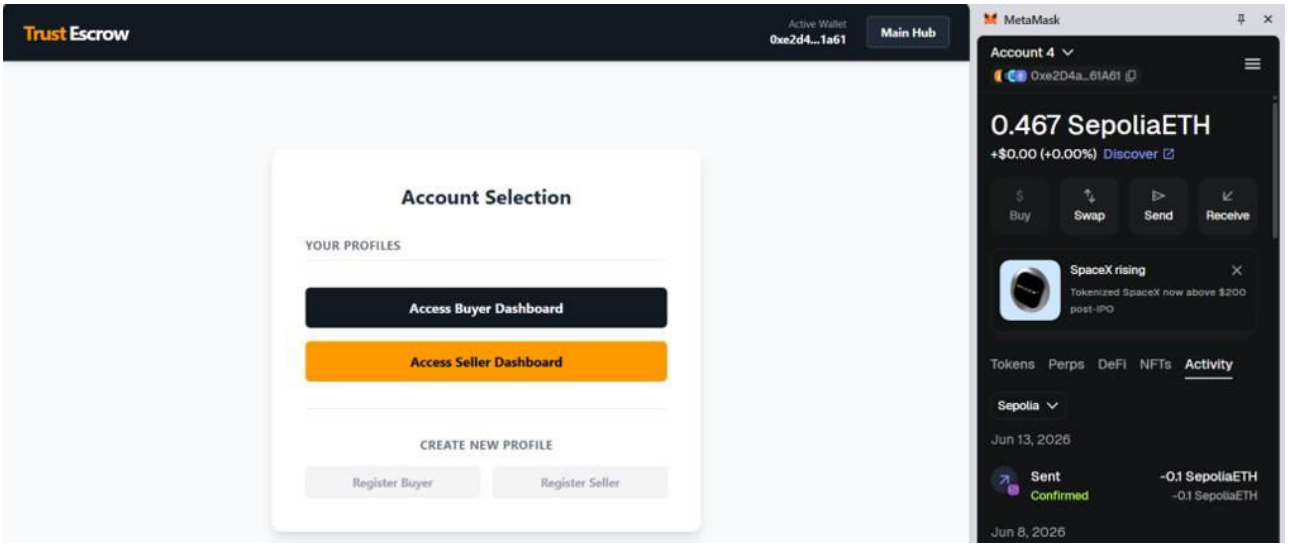

Figure 2: Account Selection & Role Registration

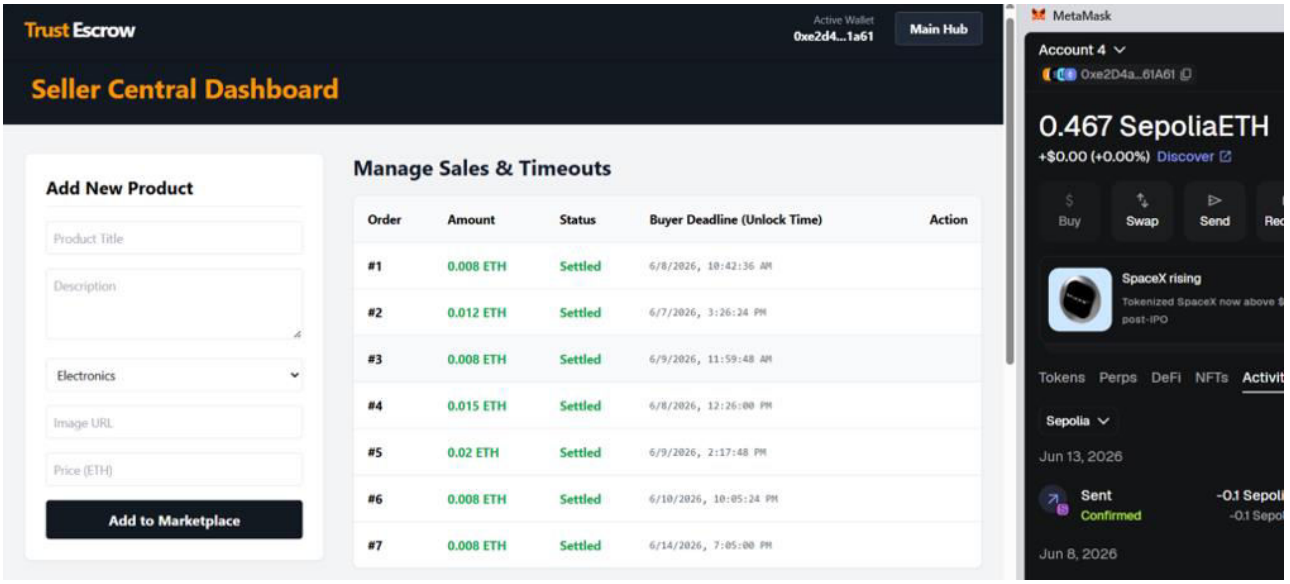

Figure 3: Seller Dashboard

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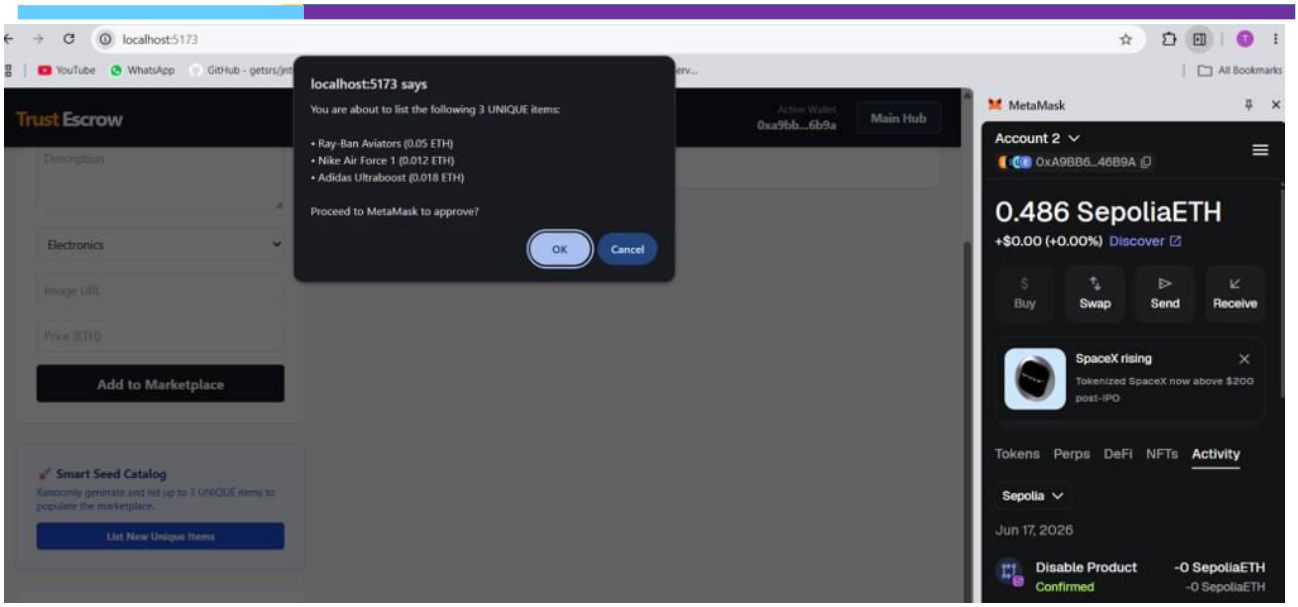

Figure 4: Active Listing of Products

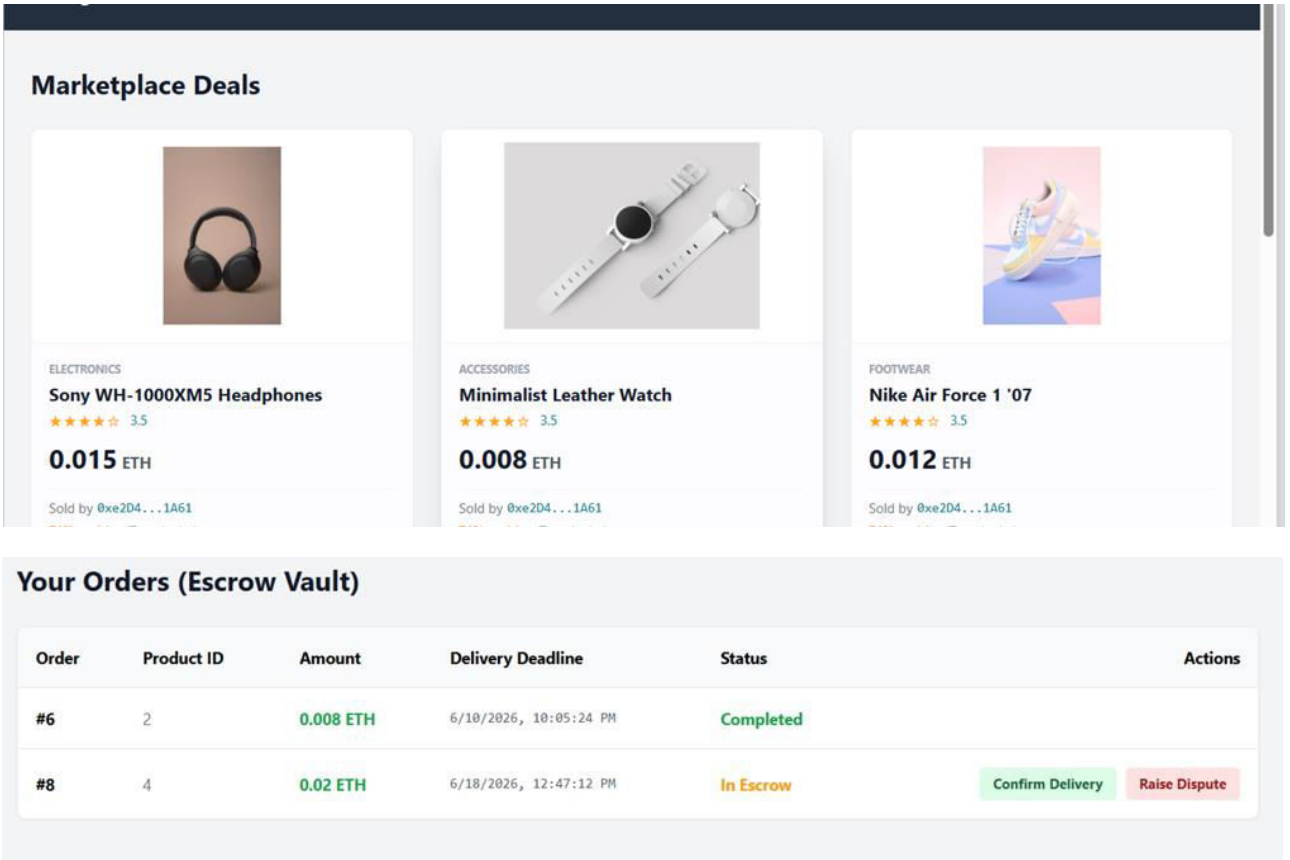

Figure 5: Buyer Dashboard & Marketplace Catalog

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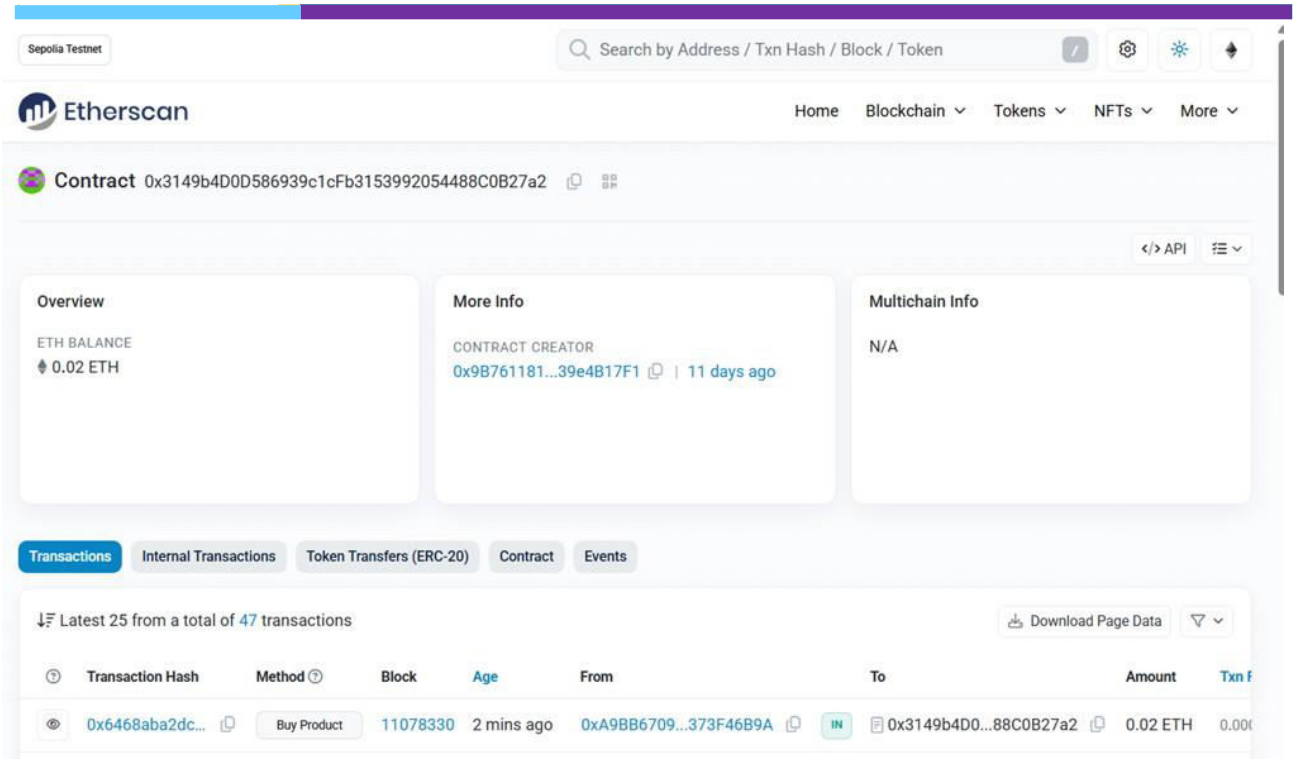

Figure 6: Etherscan Validation: Escrow Fund Locking

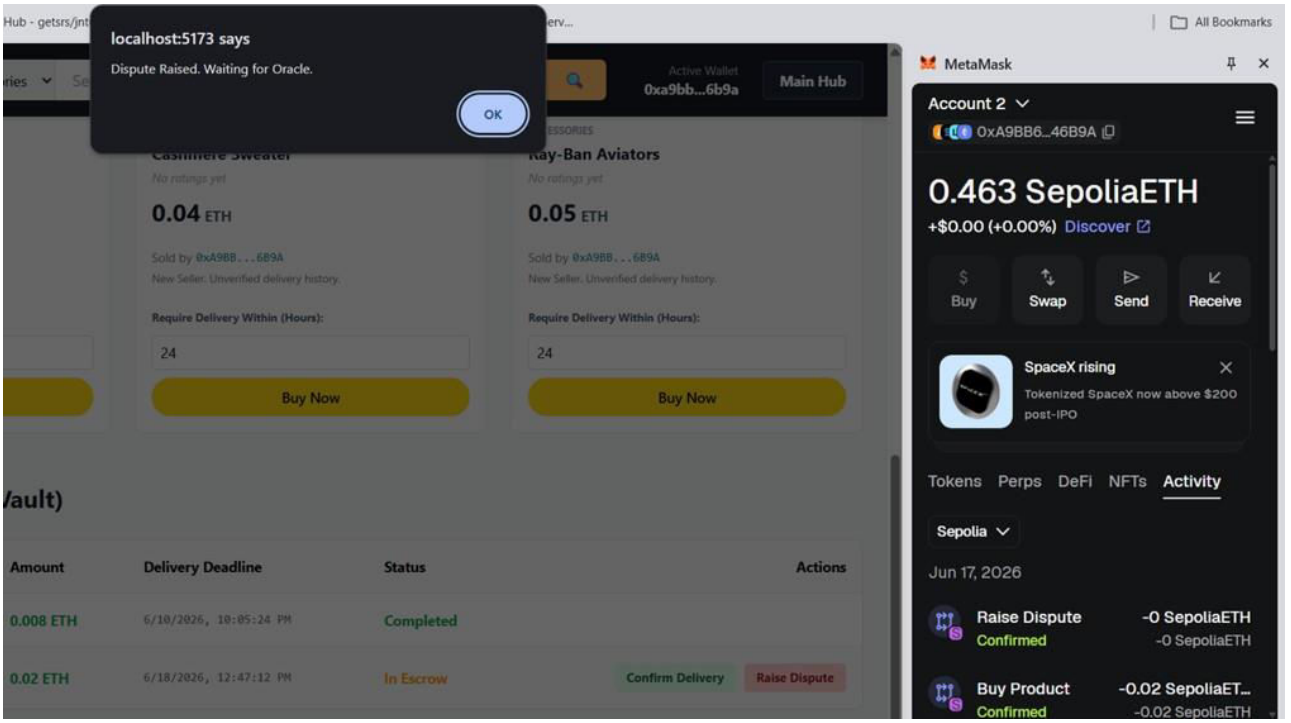

Figure 7: : Raising a Dispute

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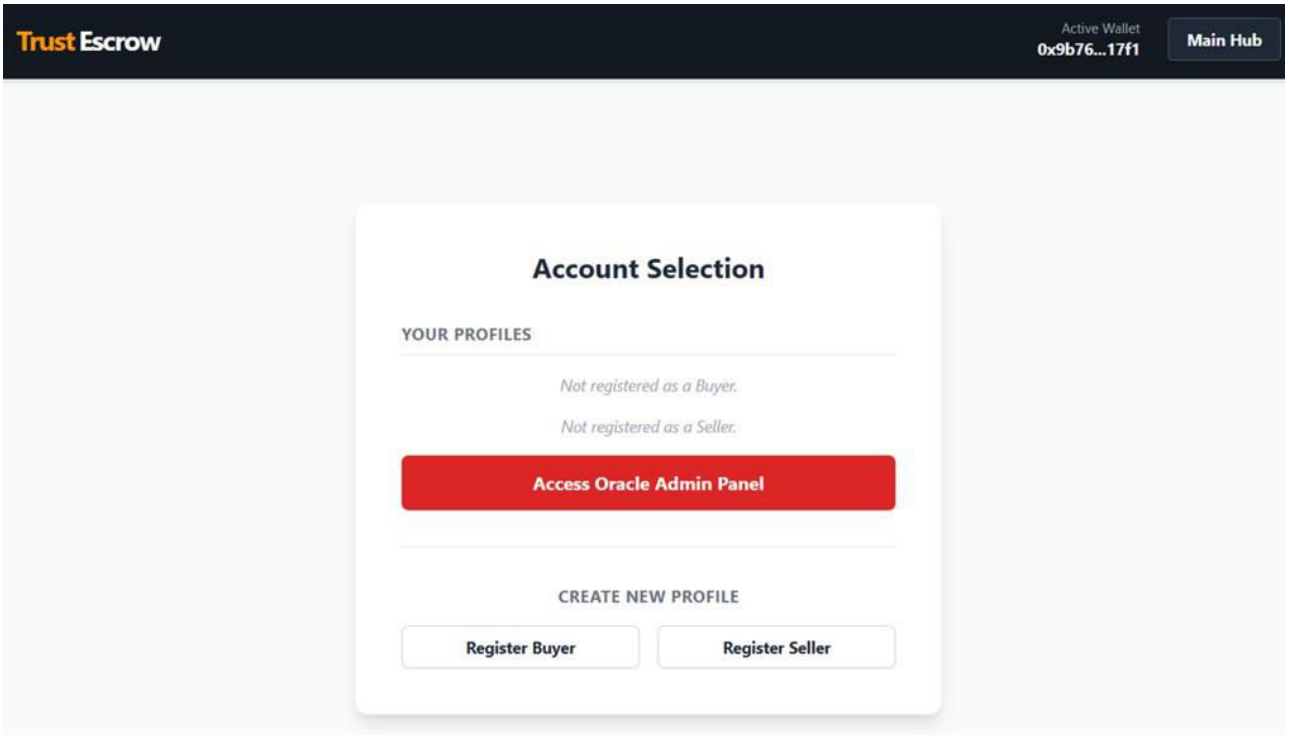

Figure 8:Oracle Dispute Resolution Center (Admin View)

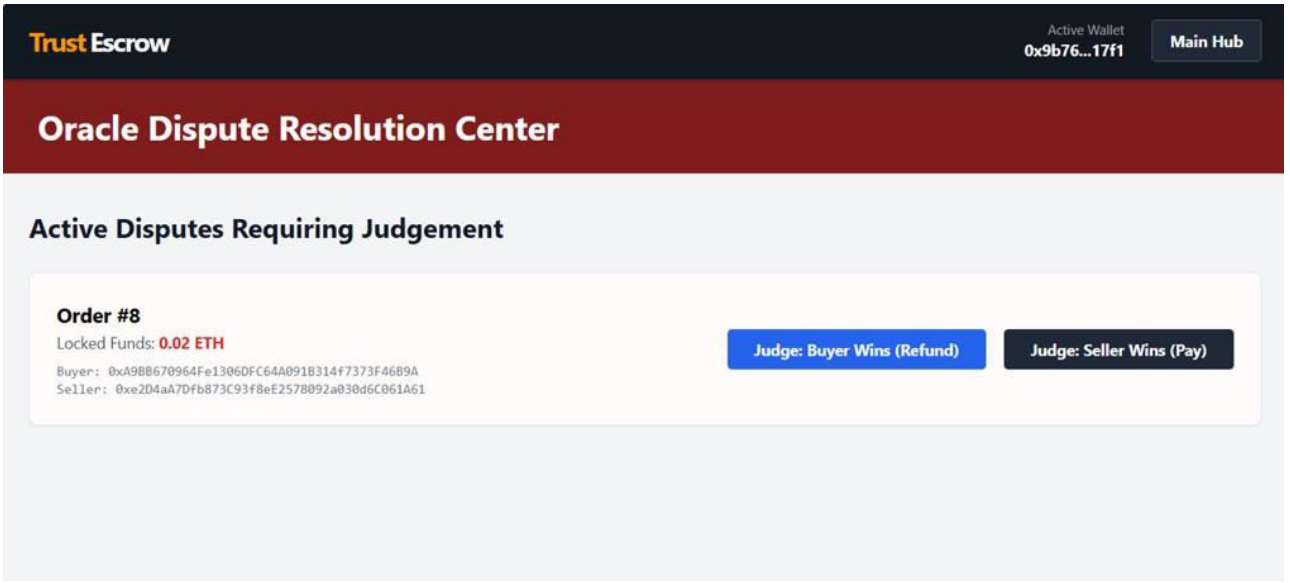

Figure 9: Admin making decision

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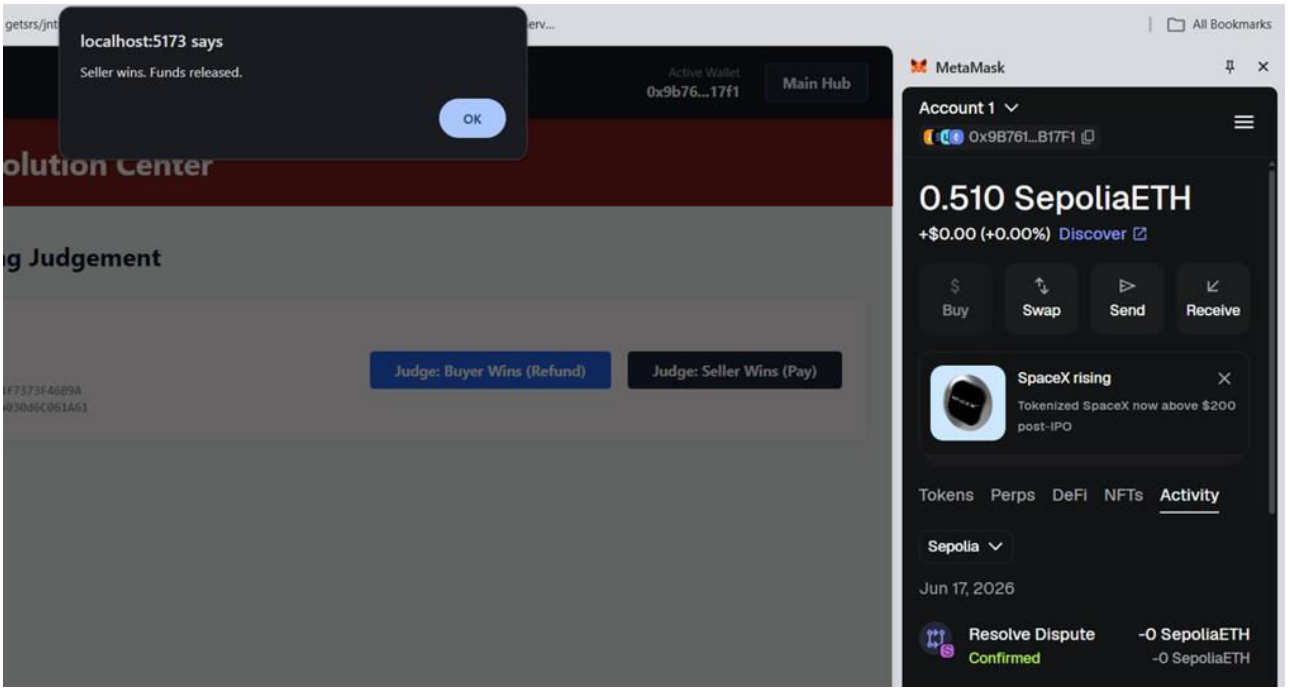

Figure 10:Releasing funds

Cost Efficiency: By eliminating the need for centralized intermediaries and automated escrow management, the protocol drastically reduces the administrative overhead and transaction fees typically associated with traditional financial escrow services.

System Reliability: Leveraging the immutable Ethereum blockchain ensures there is no single point of failure. Cryptographic role management and time-locked state machines guarantee that funds are only released under strict, mathematically verified conditions.

High-Speed Throughput: The system eliminates multi-day bank settlement delays. Upon condition fulfillment—such as buyer confirmation or Oracle resolution—funds are autonomously routed and settled within seconds, governed only by network block times.

VI. CONCLUSION

To conclude, the suggested decentralized escrow service can ensure safe transactions without involving any intermediary by employing Ethereum smart contracts. This allows us to reduce transaction costs as well as eliminate third-party involvement and fraud. It is worth noting that our solution illustrates an effective way of storing money in a safe place until the rules defined by both parties are fulfilled. The success of the delivery or failure of reaching consensus, along with the expiration of the time limit, determines whether the money is paid out from an escrow account or not.

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