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Smart Checkout System Using RFID and Blockchain Technology

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Abstract - In retail environments, long checkout queues and manual billing reduce customer satisfaction and operational efficiency. Traditional barcode-based systems require human involvement and centralized databases, which increase processing time and security risks. This paper presents a blockchain-based self-checkout system using RFID technology to automate the billing process. Each product is equipped with an RFID tag that enables contactless and fast identification. An RFID reader detects products automatically and sends data to the processing unit. Product and transaction details are stored on a blockchain network instead of a centralized database. Blockchain ensures data integrity, transparency, and resistance to tampering. Smart contracts manage billing operations and validate transactions securely. The total bill is generated in real time without manual scanning. The system significantly reduces checkout time and human errors. It also improves trust between customers and retailers. The proposed solution is suitable for smart retail environments. This system supports secure, efficient, and scalable retail automation.

1.INTRODUCTION

The retail industry is undergoing rapid transformation due to the adoption of automation and digital technologies. One of the most common challenges faced by retail stores is long waiting time at billing counters, especially during peak hours. Traditional checkout systems rely on barcode scanning and manual cashier operations, which increase processing time and often lead to billing errors. These systems also depend on centralized databases, making them vulnerable to data manipulation and single points of failure.Radio Frequency Identification (RFID) technology provides an efficient alternative to barcode-based systems by enabling contactless and fast product identification. RFID tags do not require line-of-sight scanning and can be read automatically, making them suitable for self-checkout applications. By integrating RFID with automated billing systems, customer effort and checkout delays can be significantly reduced.In addition to automation, data security and transparency have become major concerns in modern retail systems. Centralized databases are prone to unauthorized access, data tampering, and system failures. Blockchain technology offers a decentralized and secure data storage mechanism that ensures immutability and transparency of transaction records. Each transaction stored on the blockchain is verified and cannot be altered, which enhances trust between retailers and customers.This paper proposes a blockchain-based self-checkout system using RFID that combines automated product identification with secure decentralized data storage. The system aims to reduce checkout time, eliminate human intervention, prevent data tampering, and improve overall retail efficiency. The proposed solution is designed to support future smart retail environments with improved security, scalability, and reliability.

2.PROBLEM STATEMENT

Retail billing systems still depend largely on manual barcode scanning and cashier-based operations, which leads to increased checkout time and long customer queues. Such systems are inefficient during peakhours and are prone to scanning delays, human errors, and operational bottlenecks. The requirement of line-of-sight scanning further limits the speed and reliability of traditional checkout method

Most existing retail billing solutions also store transaction data in centralized databases, creating risks related to data manipulation, lack of transparency, and single-point system failure. Even though RFID technology improves product identification speed, many RFID-based systems fail to address data security and trust issues due to centralized storage.

Hence, there is a need to develop a self-checkout system using RFID combined with blockchain technology that automates the billing process while ensuring secure, decentralized, and tamper-resistant data storage. The system should reduce human involvement, improve checkout efficiency, and provide reliable transaction records suitable for modern smart retail environments.

3.LITERATURE SURVEY

R. Kumar et al. proposed an RFID-based automated billing system for retail stores. RFID tags were attached to products and scanned automatically using an RFID reader. The system reduced manual barcode scanning and checkout time, but it relied on a centralized database, which raised security and data integrity concerns.

A. Patil and S. Deshmukh developed a smart shopping system using RFID technology and embedded controllers. Their system automatically detected items placed in the cart and generated the bill in real time. Although the system improved billing efficiency, it lacked secure and tamper-proof data storage.

P. Sharma et al. presented an IoT-based retail automation system that integraRFID with cloud databases for real-time billing and inventory updates. The system improved scalability but depended on centralized cloud storage, making it vulnerable to unauthorized access.

V. Singh studied the use of blockchain technology for secure transaction management in retail systems. The research highlighted blockchain's ability to provide transparency and data immutability. However, the system did not include automated product identification such as RFID.

The review shows that RFID systems enhance billing automation while blockchain improves data security. Very limited work integrates both technologies, which motivates the proposed blockchain-based self-checkout system using RFID.

4.METHODOLOGY

The RFID-based self-checkout system integrated with blockchain technology was developed using a systematic and modular methodology. The design approach focuses on automation, security, transparency, and scalability. The overall methodology is divided into multiple phases, ensuring reliable integration of hardware, software, and blockchain components.

1. Requirement Analysis and System Planning.

The initial phase involved identifying the limitations of traditional barcode-based billing systems, such as long queues, manual errors, and lack of transaction transparency. Functional requirements were defined to automate item detection, generate real-time billing, and enable secure digital payment. Non-functional requirements such as system security, scalability, reliability, and low power consumption were also considered. Based on these requirements, NodeMCU and PN532 RFID were selected due to their compatibility with IoT and wireless communication.

2. RFID-Based Item Identification

Each product in the store is equipped with a passive RFID tag containing a unique identification number. The PN532 RFID reader is placed in a smart cart or checkout unit to detect the tags when items are added or removed. The PN532 operates using radio frequency communication, allowing contactless and line-of-sight-free scanning. The detected tag ID is transmitted to the NodeMCU via serial or I2C communication for further processing.

3. NodeMCU Processing and Data Transmission

NodeMCU (ESP8266) serves as the central processing and communication unit. Upon receiving the RFID tag ID from the PN532 module, the NodeMCU validates the data and prepares a structured request containing the tag ID and transaction status. Using built-in Wi-Fi capabilities, the NodeMCU securely transmits this data to the backend server or web dashboard using HTTP or MQTT protocols. This ensures real-time synchronization between hardware and software components.

4. Backend Server and Product Database Management

A backend server handles the business logic of the system. The server maps RFID tag IDs to corresponding product details such as item name, price, and category. The database dynamically updates the cart content and calculates the total bill. Unlike conventional centralized storage, the finalized billing and transaction records are prepared for blockchain storage to ensure immutability and transparency.

5. Blockchain-Based Payment Processing

Once the customer completes item selection, the total bill is forwarded to the blockchain payment module. A smart contract is triggered to initiate the payment process. The smart contract verifies transaction parameters such as total amount, wallet balance, and payment authorization. After validation, the payment is recorded as a blockchain transaction, generating a unique transaction hash. This process ensures decentralized, tamper-proof, and transparent payment execution without third-party interference.

6. Blockchain-Based Transaction Database

All finalized billing and payment records are stored in the blockchain ledger instead of a traditional database. Each block contains encrypted transaction data, timestamp, and cryptographic hash linking it to the previous block. This distributed ledger approach ensures data integrity, prevents unauthorized modification, and provides permanent auditability of transactions. Multiple nodes maintain synchronized copies of the ledger, eliminating single-point failures.

7. Web-Based Payment Dashboard

A web-based dashboard acts as the user interface for customers and administrators. The dashboard displays scanned items, individual prices, total bill amount, and payment status in real time. It generates a QR code or payment request linked to the blockchain transaction. Once the blockchain confirms the transaction, the dashboard updates the payment status automatically. Administrators can also monitor transaction history, billing logs, and system performance through the dashboard.

8. Security and Data Protection Mechanisms

Security is ensured at multiple levels. RFID communication is validated to prevent unauthorized tag detection. Wi-Fi data transmission from NodeMCU to the server is encrypted using secure protocols. Blockchain technology adds an additional layer of security by ensuring immutable transaction storage. Smart contracts eliminate manual verification and reduce fraud risks.

9. System Testing and Validation

The complete system is tested under real-time scenarios to evaluate RFID detection accuracy, network latency, billing correctness, and blockchain transaction confirmation time. Stress testing is performed to analyze system performance with multiple simultaneous transactions. Functional testing ensures correct item detection, billing updates, dashboard synchronization, and successful payment confirmation.

10. Deployment and Scalability Considerations

The system is designed with scalability in mind. Additional RFID readers and checkout units can be added without altering the core architecture. The blockchain network supports expansion by adding new nodes. Cloud-based hosting of the dashboard allows remote access and real-time monitoring, making the system suitable for large-scale retail environments.

5.HARDWARE DESIGN OF SMART CHECKOUT SYSTEM

1. RFID Tags (Product Identification Unit)

Smart checkout systems widely use passive UHF RFID tags for product identification. These tags operate in the frequency range of 860–960 MHz and are attached to individual products. Each tag stores a unique product ID and does not require an internal power source, as it is activated by the electromagnetic signal emitted from the RFID reader. Their low cost and maintenance-free operation make them suitable for large-scale retail environments.

2. RFID Reader (Sensing Unit)

The RFID reader functions as the sensing unit and is responsible for detecting multiple RFID tags simultaneously. It reads the unique product information stored in the tags and transmits the data to the processing unit. RFID readers are preferred in smart checkout systems due to their fast tag detection capability, support for bulk scanning,and significant reduction in checkout time compared to traditional barcode systems.

3. Processing Unit (Microcontroller / Embedded System)

The processing unit, typically implemented using platforms such as Raspberry Pi, Arduino with Wi-Fi modules, or ESP32, manages the core system operations. It processes the RFID data received from the reader, calculates the total billing amount, and prepares transaction details for further processing. These controllers are selected for their real-time processing capability, wireless communication support, low power consumption, and ease of system integration.

4. Blockchain Interface Module

In many reviewed systems, the blockchain interface is implemented using the same processing hardware along with a software layer comprising blockchain APIs and smart contracts. This module records billing transactions on a blockchain network, ensuring data immutability, transparency, and security. The integration of blockchain technology helps prevent billing fraud and enhances trust in automated checkout systems.

5. Display Unit

The display unit provides real-time information to the user during the checkout process. It shows the list of scanned products, the total payable amount, and the current payment status. This component improves user interaction, system transparency, and overall shopping experience by allowing customers to monitor their purchases instantly.

6 Payment Interface

Smart checkout systems commonly adopt cashless payment interfaces, with QR code–based payment methods being widely used. The payment interface enables customers to complete transactions digitally and verifies successful payment before finalizing checkout. This approach ensures faster transactions, reduces the need for manual intervention, and supports secure and contactless payments.

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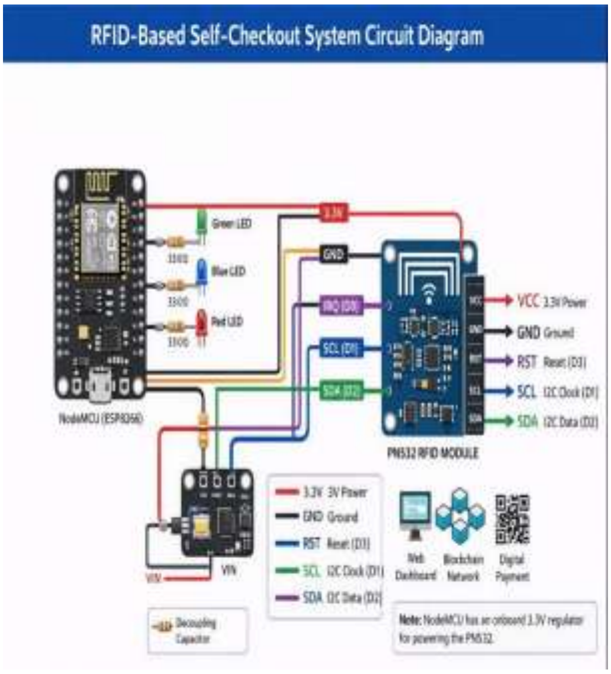
6.CIRCUIT DIAGRAM



1.NodeMCU (ESP8266) – Central Processing Unit

The NodeMCU (ESP8266) functions as the primary control and processing unit of the self-checkout system. It coordinates all system operations, including RFID data handling, billing logic execution, and communication with external software components. The embedded Wi-Fi module allows the NodeMCU to transmit real-time transaction data to the web-based payment dashboard and blockchain network.

The NodeMCU processes the unique identification code received from the RFID reader and matches it with stored product information. It also manages system timing, error handling, and data formatting. Due to its low cost, compact size, and built-in networking capability, NodeMCU is well suited for IoT-based retail automation systems.

2.PN532 RFID Module – Product Identification Unit.

The PN532 RFID module is responsible for contactless identification of products. Each product is attached with a passive RFID tag that stores a unique identifier. When the product is placed near the RFID reader, the PN532 detects the tag and reads its identification data using radio frequency communication.

7. HARDWARE DESCRIPTION

The circuit diagram of the RFID-based self-checkout system represents the integration of essential hardware components required for automatic product identification, billing, and wireless communication. The design focuses on simplicity, low power consumption, and reliable operation in a smart retail environment. The core hardware units include the NodeMCU

(ESP8266), PN532 RFID module, power supply unit, and system status indicator

This module eliminates the need for line-of-sight scanning, unlike barcode systems. It supports fast and reliable detection, enabling smooth and error-free product recognition. The PN532 transfers the tag information to the NodeMCU for further processing, forming the foundation of the automated billing system.

3.Power Supply Unit

A stable power supply is essential for consistent system performance. The NodeMCU is powered using a regulated power source, which ensures reliable operation during continuous RFID scanning and wireless communication. The onboard voltage regulation circuitry of the NodeMCU provides the required operating voltage to the PN532 RFID module.

Proper power management prevents voltage fluctuations that could cause system resets or incorrect tag readings. The power unit is designed to support prolonged operation, making the system suitable for real-world retail environments.

4.System Status Indicator LEDs

System status indicator LEDs are incorporated to provide visual feedback regarding the operational state of the self-checkout system. These indicators help users and administrators quickly understand system behavior without requiring a display interface.

The green indicator signals successful RFID tag detection, confirming that a product has been correctly identified. The blue indicator represents active network connectivity and successful communication with the dashboard. The red indicator alerts the user to error conditions such as invalid tag detection or system faults. These indicators enhance usability and improve fault diagnosis.

5.Overall Hardware Operation Flow

The overall hardware operation begins when a product carrying an RFID tag is brought near the PN532 reader. The RFID module reads the tag's unique identification code and forwards it to the NodeMCU. The NodeMCU processes this data, verifies the product information, and updates the billing logic accordingly.

Once processed, the transaction data is transmitted wirelessly to the web-based payment dashboard. The system then prepares the data for blockchain-based payment processing. Throughout this operation, the indicator LEDs provide real-time feedback on system status, ensuring smooth and transparent operation.

7.ADVANTAGES

1.Automated and Fast Checkout Process

The RFID-based self-checkout system enables automatic identification of products without manual scanning. Multiple items can be detected quickly, significantly reducing billing time and eliminating long queues at checkout counters. This improves overall shopping efficiency.

2.Contactless and User-Friendly Operation

Since RFID technology works without physical contact or line-of-sight scanning, the system supports hygienic and contactless shopping. Customers can complete the checkout process independently using the payment dashboard, enhancing user convenience.

3.Reduced Human Intervention and Operational Cost.

The system minimizes the need for cashier assistance, reducing labor dependency and operational costs for retail stores. Automated billing and payment processing also reduce human errors during transactions.

4.Real-Time Billing and Payment Transparency

The integration of a web-based dashboard allows customers to view scanned items, total amount, and payment status in real time. Blockchain technology ensures transparent and tamper-proof storage of transaction records.

5.Secure and Tamper-Proof Transactions Using Blockchain

Blockchain-based payment and data storage provide high security by maintaining immutable transaction records. Each transaction is cryptographically secured, preventing data manipulation and fraud.

6.Scalable and IoT-Enabled Architecture

The use of NodeMCU (ESP8266) enables seamless integration with IoT platforms. Additional checkout units and RFID readers can be deployed without major architectural changes, making the system scalable.

7.Improved Inventory Tracking

Every scanned RFID tag updates the system database automatically. This helps retailers maintain accurate inventory records, detect stock shortages, and reduce losses due to theft or mismanagement.

8.Enhanced Customer Experience

Faster checkout, reduced waiting time, and digital payment options improve overall customer satisfaction and encourage repeat visits.

8. DISADVANTAGES

1.Initial Setup Cost

The initial installation cost of RFID hardware and system integration is comparatively higher than conventional barcode systems.

2.Dependence on Internet Connectivity

The system requires a stable internet connection for real-time dashboard updates and blockchain-based payment processing.

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3.RFID Signal Interference

In rare cases, environmental factors may affect RFID signal performance, which can be minimized through proper system design.

4.System Maintenance Requirement

Periodic maintenance of hardware and software components is required to ensure smooth operation.

9.CONCLUSION

This review highlights an RFID-based self-checkout system that enhances efficiency, security, and user convenience in retail environments. By combining RFID technology with NodeMCU (ESP8266) and the PN532 module, the system enables fast and contactless product identification, eliminating the delays of barcode-based billing. Automated item detection significantly reduces checkout time and improves the overall shopping experience.

The integration of a web-based payment dashboard allows customers to monitor billing details and complete transactions independently. The use of blockchain technology further strengthens transaction security and data integrity by ensuring transparency and resistance to unauthorized modifications. Wireless IoT connectivity through NodeMCU supports scalability and real-time communication, making the system suitable for modern retail automation.

Despite minor challenges such as initial deployment cost and network dependency, the advantages outweigh the limitations. Overall, the proposed RFID self-checkout system with blockchain support offers a secure, efficient, and future-oriented solution for smart retail systems.

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