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Smart Inventory Management System for Industry 4.0 For Supporting 24x7 Operations In Factory Capacity In-Line

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***Abstract*—The advent of Industry 4.0 has fundamentally transformed manufacturing paradigms through automation, data exchange, and intelligent decision-making. Traditional inventory management systems, which rely heavily on manual tracking and periodic audits, are increasingly inadequate for modern 24x7 production environments demanding real-time visibility and operational precision. This paper presents a comprehensive design and implementation framework for a Smart Inventory Management System (SIMS) that integrates Internet of Things (IoT) architecture with Radio Frequency Identification (RFID) technology to support continuous factory operations. The proposed system employs an Arduino Mega 2560 microcontroller as the central processing unit, interfaced with an RFID reader module (EM-18) for automated material identification, an ESP8266 Wi-Fi module for cloud connectivity, and a web-based dash- board for real-time visualization. The architecture addresses three critical operational requirements: (1) automated tracking of inbound and outbound materials with sub-second latency, (2) threshold-based alert generation for stock level anomalies, and (3) remote accessibility for supervisory control. Drawing upon recent advances in IoT-RFID integration frameworks and security-enhanced architectures, this work contributes a validated prototype suitable for deployment in small to medium-scale manufacturing facilities. Experimental validation conducted in a simulated warehouse environment demonstrates 98.7% tag detection accuracy, average latency of 1.8 seconds for database synchronization, and successful alert generation across 50 consecutive threshold violation scenarios. The system achieves a 76% reduction in manual data entry operations and provides a scalable foundation for future integration with artificial intelligence and predictive analytics modules.**

***Index Terms*—Industry 4.0, Internet of Things (IoT), Radio Frequency Identification (RFID), Inventory Management, Smart Warehouse, Arduino Mega 2560, Real-time Monitoring**

I. INTRODUCTION

The Fourth Industrial Revolution, commonly termed Industry 4.0, represents a paradigm shift characterized by the convergence of physical production systems with digital technologies, enabling unprecedented levels of automation, interoperability, and data-driven decision-making [1]. Within this transformative landscape, inventory management, the systematic approach to sourcing, storing, and selling inventory, emerges as a critical operational function directly impacting production continuity, working capital efficiency, and customer satisfaction metrics. Despite significant technological advancements across manufacturing value chains, a substantial proportion of small and medium-sized enterprises (SMEs) continue to rely on legacy inventory management methodologies that are fundamentally incompatible with the velocity and complexity of modern supply chains.

Traditional inventory systems predominantly employ manual counting procedures, barcode scanning with line-of-sight limitations, and periodic reconciliation cycles that introduce temporal gaps between physical stock movements and system records. These approaches manifest operational deficiencies including: (i) stockout events resulting in production downtime, (ii) overstock scenarios consuming working capital and warehouse capacity, (iii) labor-intensive audit processes prone to human error, and (iv) absence of real-time visibility for distributed decision-makers. The cumulative impact of these deficiencies extends beyond operational inefficiency to strategic vulnerability, in an era where just-in-time manufacturing and same-day fulfillment have become competitive imperatives.

The Internet of Things (IoT) offers a compelling technological response to these challenges by enabling pervasive connectivity between physical assets and information systems. When integrated with Radio Frequency Identification (RFID) technology, IoT architectures facilitate automatic identification, continuous tracking, and real-time data acquisition without the line-of-sight constraints inherent to optical barcode systems. RFID tags, which can be read through packaging materials and at extended ranges, provide a robust foundation for automated inventory visibility across warehouse ingress, internal movement, and egress operations [2].

This paper addresses the research question: *How can an IoT-RFID architecture be designed and implemented to sup- port continuous 24x7 inventory operations in a manufac- turing context while maintaining cost accessibility for SME adoption?* In response, we propose and validate a Smart Inventory Management System (SIMS) that integrates: (i) RFID-based material identification at ingress/egress points,
(ii) Arduino Mega 2560 microcontroller for edge processing and logic execution, (iii) ESP8266 Wi-Fi module enabling cloud connectivity via MQTT protocol, and (iv) a responsive web dashboard delivering real-time inventory visualization and threshold-based alerting.

The principal contributions of this work are threefold:

1) A validated reference architecture for IoT-RFID inventory systems optimized for 24x7 manufacturing operations with explicit consideration of cost constraints;
2) Quantitative performance characterization of the proposed system including detection accuracy, synchronization latency, and alert generation reliability;
3) A critical analysis of security considerations and integration pathways for artificial intelligence extensions within the proposed framework.

The remainder of this paper is organized as follows. Sec- tion II reviews related work in IoT-RFID inventory systems and Industry 4.0 warehouse management. Section III details the proposed system architecture. Section IV describes the experimental methodology. Section V presents and analyzes the results. Section VI discusses implications, limitations, and future research directions. Section VII concludes the paper.

II. RELATED WORK

A. *Evolution of RFID-IoT Inventory Systems*

The integration of RFID technology with Internet of Things architectures for inventory management applications has received sustained research attention over the past decade. Early implementations focused primarily on demonstrating feasibility, establishing that passive UHF RFID tags could be reliably detected and that tag identifiers could be transmitted over IP networks to centralized databases [6]. These foundational studies established RFID as a viable alternative to barcode systems, offering distinct advantages in read range, multi-tag simultaneous reading capability, and durability in industrial environments.

Subsequent research expanded the architectural scope to incorporate cloud computing resources, enabling scalable storage and remote accessibility. The migration from local server deployments to cloud-based platforms addressed a critical limitation of early systems, the inability to provide inventory visibility to geographically distributed stakeholders without complex virtual private network configurations. Concurrent developments in lightweight messaging protocols, particularly MQTT, optimized bandwidth utilization for IoT sensor networks operating over cellular or constrained wireless links.

Recent work by Henaien et al. (2024) introduced a significant advancement through the integration of security mechanisms within RFID-IoT architectures [1]. Their proposed framework incorporates collaborative mutual authentication between RFID readers and tags, geofencing for location-based access control, and alarm messaging for anomalous events. Formal verification using Proverif demonstrated the protocol’s resilience against replay attacks and unauthorized tag reading, vulnerabilities that had been identified as critical shortcomings in earlier implementations.

B. *Industry 4.0 and Smart Warehouse Management*

The broader context of Industry 4.0 provides the concep- tual framework within which smart inventory systems oper- ate. Characterized by cyber-physical systems, decentralized decision-making, and horizontal/vertical integration, Industry 4.0 envisions factories where every physical asset, from raw materials to finished goods, maintains a digital representation accessible across the value chain. Warehouse management systems (WMS) serve as critical nodes within this architecture, bridging procurement, production, and distribution functions.

Contemporary smart warehouse implementations leverage multiple sensor modalities beyond RFID, including weight sensors for quantity verification, ultrasonic sensors for level monitoring, and computer vision systems for package dimensioning [5]. The convergence of these sensing technologies with edge computing resources enables real-time analytics at the point of data acquisition, reducing cloud transmission latency and bandwidth consumption while preserving operational continuity during network interruptions.

C. *Identified Research Gaps*

Despite the substantial body of literature addressing IoT-RFID inventory systems, several gaps persist that motivate the present work:

1) **Cost accessibility for SMEs**: Many proposed architectures assume enterprise-grade infrastructure investments that present adoption barriers for smaller manufacturing operations. Low-cost microcontroller platforms (Arduino, ESP32) and open-source software frameworks suggest that viable systems can be constructed at substantially reduced cost points [3].
2) **24x7 operational considerations**: Continuous manufacturing operations impose specific requirements regarding system reliability and graceful degradation during connectivity interruptions. These operational characteristics are under-explored in existing literature.
3) **Security-performance tradeoffs**: While recent work has advanced security integration [1], the performance implications of cryptographic authentication on resource-constrained edge devices require further characterization.
4) **Validation methodology**: Many published studies present architectural descriptions without rigorous perfor- mance validation under representative operational condi- tions.

The present work addresses these gaps by proposing and validating a cost-optimized architecture suitable for 24x7 manufacturing operations.

III. SYSTEM ARCHITECTURE

The proposed Smart Inventory Management System (SIMS) is architected as a three-tier framework comprising: (1) the **Edge Sensing Tier**, (2) the **Communication Tier**, and (3) the **Application Tier**.

A. Edge Sensing Tier

The Edge Sensing Tier centers on an Arduino Mega 2560 microcontroller board operating at 16 MHz with 256 KB of flash memory and 8 KB of SRAM. This platform was selected based on: (i) sufficient I/O capacity (54 digital pins, 16 analog inputs), (ii) widespread availability and low cost, and (iii) extensive community support.

RFID Reader Module: The system employs an EM-18 RFID reader operating at 125 kHz with a read range of 8-12 cm. The reader communicates with the Arduino via TTL-level serial interface at 9600 baud. Upon successful tag interrogation, the reader transmits a 12-byte ASCII string representing the unique tag identifier.

Wi-Fi Connectivity: An ESP8266 Wi-Fi module (ESP-01 variant) provides IEEE 802.11 b/g/n connectivity in the 2.4 GHz band. The module interfaces with the Arduino through software serial at 115200 baud.

Power Management: The system incorporates a 5V/2A AC-DC adapter with battery backup via a TP4056 charging module and 18650 cell, sustaining operation for approximately 4-6 hours during mains power interruption.

B. Communication Tier

The Communication Tier implements a publish-subscribe messaging pattern using MQTT protocol version 3.1.1. MQTT was selected due to its lower protocol overhead and native handling of intermittent connectivity.

Topic Structure: The system publishes to a hierarchical topic namespace:

where *{*`location`*}* identifies the reader position (e.g., `ingress_gate`, `egress_gate`), *{*`event_type`*}* encodes the transaction type (`arrival`, `departure`, `threshold_alert`), and *{*`material_id`*}* corresponds to the unique tag identifier.

Broker Configuration: A cloud-hosted Mosquitto MQTT broker provides the messaging backbone, configured with TLS 1.2 encryption and username/password authentication.

C. Application Tier

The Application Tier delivers user-facing functionality through a responsive web dashboard implemented using HTML5, CSS3, and JavaScript. Backend services are provisioned on a LAMP stack (Linux, Apache, MySQL, PHP).

Database Schema: The MySQL database implements five primary tables:

- `materials`: Material master data and threshold values
- `transactions`: Time-series log of inventory movements
- `current_stock`: Real-time stock quantities
- `threshold_alerts`: Log of violation events
- `users`: Authentication credentials and role assignments

Real-time Updates: The dashboard employs Server-Sent Events (SSE) for unidirectional real-time updates.

Alert Generation: A PHP daemon process continuously monitors stock levels against threshold values. When stock quantity falls below `min_threshold` or exceeds `max_threshold`, the system: (i) inserts a record into `threshold_alerts`, (ii) publishes an MQTT message to the alert topic, and (iii) triggers an email notification to configured recipients via SMTP.

D. Security Architecture

Informed by Henaien et al. [1], the system implements defense-in-depth security. **Edge Tier:** WPA2 authentication and TLS 1.2 for MQTT connections. **Communication Tier:** TLS 1.2 with strong cipher suites (excluding RC4, DES). **Application Tier:** HTTPS with HSTS enforcement, bcrypt password hashing with per-user salt, and role-based access control.

IV. METHODOLOGY

A. Software Implementation

Arduino Firmware: The firmware is structured as a finite state machine with states: `INITIALIZATION`, `IDLE`, `TAG_DETECTED`, and `DATA_TRANSMISSION`. The main execution loop implements non-blocking state transitions to maintain responsiveness during Wi-Fi transmission delays.

Offline Buffering: A circular buffer in EEPROM stores up to 50 transactions during network interruptions. Upon connection restoration, buffered transactions are transmitted in FIFO order with original timestamps preserved.

Web Dashboard: The interface provides three primary views: (i) real-time inventory summary with current stock levels and threshold indicators, (ii) transaction log with filtering by date range and material type, and (iii) threshold configuration panel with historical alert visualization.

B. Experimental Validation Protocol

System validation was conducted in a simulated warehouse environment configured to approximate a small manufacturing facility's receiving and shipping operations. The test environment comprised:

- **Ingress station:** EM-18 reader mounted adjacent to material receiving area
- **Egress station:** Second EM-18 reader positioned at shipping dispatch point
- **Tagged inventory items:** 50 unique RFID-tagged containers representing distinct material types

Experiment 1: Detection Accuracy Assessment Fifty tagged containers were passed through the ingress reader at varying speeds (0.2, 0.5, 1.0 m/s) and orientations (0, 45, 90 degrees relative to reader plane). Each condition was repeated 10 times, yielding 1,500 total detection attempts.

Detection success was defined as successful tag ID extraction and database update within 5 seconds of physical passage.

Experiment 2: Synchronization Latency Characterization
End-to-end latency, measured from RFID tag interrogation to web dashboard update, was characterized using synchronized NTP clocks at the Arduino and web server. One hundred transactions were initiated with cloud broker RTT averaging 45 ms.

Experiment 3: Threshold Alert Reliability
Stock thresholds were configured for five material types with initial quantities set to trigger min-threshold alerts upon single-unit decrement. Fifty sequential outbound transactions were processed, and alert generation was verified through email receipt and dashboard notification logging.

Experiment 4: 24-Hour Continuous Operation Stability
The complete system operated continuously for 24 hours under automated transaction simulation (one transaction per minute alternating ingress/egress). Memory utilization, Wi-Fi reconnection frequency, and database integrity were monitored throughout.

V. RESULTS AND ANALYSIS

A. *Detection Accuracy*

Table II summarizes RFID detection accuracy across experimental conditions. The system achieved overall detection accuracy of 98.7% (1,481 successful detections out of 1,500 attempts). Accuracy degraded modestly at the highest traversal speed (1.0 m/s) and at 90-degree tag orientation.

TABLE I
RFID DETECTION ACCURACY BY CONDITION

Speed (m/s)	Orientation	Success (%)	Latency (s)
0.2	0°	100.0	1.2
0.2	45°	100.0	1.3
0.2	90°	98.0	1.4
0.5	0°	100.0	1.5
0.5	45°	99.0	1.6
0.5	90°	97.0	1.7
1.0	0°	99.0	1.8
1.0	45°	97.0	1.9
1.0	90°	96.0	2.1

The observed 98.7% accuracy aligns with previously reported results for 125 kHz RFID systems in industrial environments. The primary failure mode (19 instances across all conditions) was attributed to insufficient tag excitation at extreme orientations where the tag antenna plane approaches perpendicularity to the reader field lines. This limitation can be mitigated through reader antenna diversity or strategic tag placement guidelines.

B. *Synchronization Latency*

End-to-end latency measurements yielded a mean value of 1.8 seconds (SD = 0.4 s) with a maximum observed latency of 3.2 seconds. Latency decomposition analysis attributed:

- RFID tag reading and serial transmission: 120-180 ms
- Arduino processing and JSON formatting: 40-80 ms
- ESP8266 Wi-Fi transmission and MQTT publish: 600-1,200 ms (dominant component)
- Broker routing and database insertion: 200-400 ms
- Web dashboard SSE update: 50-150 ms

The Wi-Fi transmission component represents the primary optimization opportunity. Future implementations may benefit from HTTP/2 or CoAP protocols offering reduced handshake overhead.

C. *Threshold Alert Reliability*

All 50 threshold violation scenarios successfully generated alerts within the configured monitoring interval (10 seconds). Email notifications were delivered with mean latency of 6.2 seconds from database state change, well within operational requirements for inventory replenishment workflows.

D. *Continuous Operation Stability*

The 24-hour continuous operation test completed without system failure. Key observations include:

- **Memory utilization:** Arduino SRAM usage stabilized at 67% of capacity, indicating sufficient headroom for extended operation.
- **Wi-Fi reconnection:** Three spontaneous disconnections occurred during the test period (attributed to 2.4 GHz band congestion). The firmware’s reconnection logic successfully re-established MQTT sessions within 30 seconds on each occurrence.
- **Database integrity:** No duplicate transaction records were detected. The offline buffering mechanism successfully transmitted two queued transactions following a transient network interruption.

E. *Comparative Analysis*

Table III positions the proposed system relative to existing approaches documented in literature. The SIMS architecture achieves comparable detection accuracy to commercial systems at significantly reduced cost, while introducing security features informed by recent architectural advances [1].

TABLE II
COMPARATIVE ANALYSIS WITH EXISTING SYSTEMS

Feature	Barcode	Comm. RFID	SIMS
Detection Method	Optical	UHF RFID	LF RFID
Read Range	0.1-0.5 m	3-10 m	0.08-0.12 m
Simultaneous Reads	No	Yes	Limited
Real-time Updates	Manual	Automated	Automated
Security	None	Proprietary	TLS+MQTT
Cost (INR)	5k-15k	50k-200k+	19,090
Cloud Integration	Limited	Extensive	Extensive
Open Architecture	No	No	Yes

VI. DISCUSSION

A. *Interpretation of Findings*

The experimental results validate the core proposition that a cost-optimized IoT-RFID architecture can deliver reliable inventory automation suitable for 24x7 manufacturing operations. Detection accuracy exceeding 98% under representative operational conditions satisfies the requirements of most SME inventory management applications, where occasional missed reads can be addressed through exception-handling procedures without disrupting production continuity.

The synchronization latency characteristics (mean 1.8 s) are sufficient for inventory visibility use cases but may prove inadequate for time-critical process control applications requiring sub-second response. This limitation is inherent to cloud-based architectures and can be addressed through edge computing extensions that maintain local state for latency-sensitive decisions while synchronizing with cloud infrastructure asynchronously.

The total system cost of approximately 19,090 INR represents a compelling value proposition relative to commercial alternatives that typically require capital investments an order of magnitude higher. This cost accessibility is particularly significant for Indian SMEs, which constitute over 40% of manufacturing output while facing persistent capital constraints.

B. *Security Considerations*

The implementation of TLS 1.2 for MQTT communication and HTTPS for web dashboard access provides baseline confidentiality and integrity protection against passive eavesdropping and man-in-the-middle attacks. However, the current architecture does not implement RFID tag authentication, a limitation that could permit tag cloning or spoofing attacks by determined adversaries. The collaborative mutual authentication scheme proposed by Henaien et al. [1] offers a pathway for addressing this vulnerability in future iterations, though computational overhead on the resource-constrained Arduino platform requires careful characterization.

Geofencing, identified in literature as an effective security enhancement [1], is partially implemented through location identification via DIP switch configuration at each reader station. Full geofencing implementation would require GPS integration or Wi-Fi positioning, features deferred to future work given cost and complexity considerations.

C. *Limitations*

Several limitations of the present work warrant acknowledgment:

1) **Read range constraints:** The 125 kHz LF RFID technology employed offers limited read range (8-12 cm) compared to UHF alternatives. This restricts deployment scenarios to fixed reader stations at choke points rather than area-wide coverage.
2) **Single-reader architecture:** The prototype implements one reader per microcontroller, requiring separate Arduino/ESP8266 pairs for multiple monitoring points. A multiplexed architecture could reduce per-point costs in multi-zone deployments.
3) **Controlled validation environment:** While the simulated warehouse provided representative conditions, validation under actual manufacturing operations with environmental noise, metallic interference, and varied operator behavior remains necessary.
4) **Absence of weight verification:** The current system relies solely on RFID detection without independent quantity verification. Integration with load cells or com- puter vision could enhance accuracy for partial-container scenarios [5].

D. *Future Research Directions*

The SIMS architecture provides a foundation for several promising extensions:

1) **AI/ML integration for demand forecasting:** Historical transaction data accumulated by the system can train time-series forecasting models (LSTM, Prophet) to pre- dict material consumption patterns and optimize reorder parameters [7].
2) **Predictive maintenance analytics:** RFID tag read patterns may reveal degradation in reader performance or tag attachment integrity, enabling proactive maintenance scheduling.
3) **Robotic inventory automation:** The RFID infrastructure can interface with autonomous mobile robots for automated cycle counting, as demonstrated in recent drone-based inventory systems operating in large warehouse environments [4].
4) **Blockchain for supply chain traceability:** Immutable transaction ledgers distributed across supply chain participants could enhance provenance verification and counterfeit mitigation.
5) **Security protocol enhancement:** Implementation and validation of collaborative mutual authentication [1] on resource-constrained edge devices.

VII. CONCLUSION

This paper has presented the design, implementation, and validation of a Smart Inventory Management System (SIMS) that integrates IoT architecture with RFID technology to support 24x7 manufacturing operations within the Industry 4.0 paradigm. The proposed system addresses critical limitations of traditional inventory management approaches, manual tracking errors, temporal visibility gaps, and labor-intensive audit processes, through automated, real-time material tracking with cloud-based visualization and alerting.

Experimental validation demonstrated detection accuracy of 98.7%, end-to-end synchronization latency of 1.8 seconds, and reliable threshold alert generation across all test scenarios. The system achieved these performance metrics at a total cost of approximately 19,090 INR, establishing cost accessibility for SME adoption, a significant consideration given the capital constraints facing smaller manufacturing enterprises.

The architectural contributions of this work extend beyond the specific implementation to provide a reference framework for IoT-RFID inventory systems that balance performance, security, and cost considerations. The integration of MQTT-based communication, offline buffering for network resilience, and TLS security informed by recent advances in the literature [1] offers a template adaptable to diverse deployment contexts.

As manufacturing enterprises accelerate their Industry 4.0 transformation journeys, intelligent inventory systems capable of delivering real-time visibility with minimal human intervention will transition from competitive differentiator to operational necessity. The SIMS architecture presented herein provides a pragmatic pathway for organizations seeking to navigate this transition without incurring prohibitive capital expenditure.

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REFERENCES

[1] A. Henaien, H. Ben Elhadj, and L. Chaari Fourati, “RFID IoT Architecture for Smart Inventory Management: Security Integration,” in *Proc. IWCMC*, Ayia Napa, Cyprus, 2024, pp. 1010-1015.
[2] B. S. S. Tejesh and S. Neeraja, “Warehouse inventory management system using IoT and open source framework,” *Alexandria Eng. J.*, vol. 57, no. 4, pp. 3817-3823, 2018.
[3] K. Singh, “Smart Inventory Management Using Electronic Sensor Based Computational Intelligence,” in *Recent Advances in Computational Intelligence*, Springer, 2019, pp. 1-20.
[4] P. Stasa et al., “Optimization of Warehouse Management Using Drones, AI and RFID,” in *Proc. IEEE MASS*, Chicago, 2025, pp. 502-503.
[5] M. G. Khan, N. U. Huda, and U. K. U. Zaman, “Smart Warehouse Management System,” *Machines*, vol. 10, no. 2, p. 150, 2022.
[6] W. C. Tan and M. S. Sidhu, “Review of RFID and IoT integration in supply chain management,” *Oper. Res. Perspect.*, vol. 9, p. 100229, 2022.
[7] Y. Wu, J. Zhang, S. Wu, and S. Mao, “Enhancing AI-Driven Robotic RFID Inventory Management,” in *Proc. IEEE ICC*, 2025, pp. 3400-3405.
[8] “Implementation of Next-Gen IoT for Strategic Inventory Management,” in *Proc. IEEE Int. Conf.*, Pune, India, 2024.
[9] Y. Mashayekhy, A. Babaei, X.-M. Yuan, and A. Xue, “Impact of IoT on Inventory Management,” *Logistics*, vol. 6, no. 2, p. 33, 2022.