Seaport Management Information System focusing on Cargo Tracking Using RFID Technology

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Abstract- ***This research focuses on the design and implementation of a Real-Time Seaport Management Information System with core functionality in tracking, As modern seaports face rising challenges from increased cargo traffic, security threats, and operational inefficiencies, this study proposes an intelligent, automated solution tailored to enhance Nigerian seaport operations. The system employs a modular architecture integrating RFID tracking devices, IP-based surveillance cameras, and AI-driven analytics to monitor cargo movement and detect security breaches. An Agile software model was adopted to ensure scalability and real-time responsiveness. RFID technology was integrated for cargo tracking, After simulation of the hardware components using proteus software models, the results demonstrated significant improvements in operational efficiency, with cargo tracking time reduced by 35%, The system successfully detected and flagged unauthorized activities and abnormal cargo handling in simulated tests environment, proving its effectiveness in enhancing port security. The proposed system bridges the gap between traditional seaport operations and modern digital transformation needs by providing real-time visibility, proactive threat detection, and integration among other stakeholder's activities. This Research is significant for advancing Nigerian Seaport infrastructure, promoting safer and more efficient trade operations, and setting a foundation for future smart port innovations.***

Indexed Terms- ***Real-Time, Cargo Tracking, Security, Port Operations, optimized resource allocation.***

I. INTRODUCTION

Seaports play a pivotal role in global trade by facilitating the efficient movement of cargo between maritime and inland transport systems. As critical nodes in international supply chains, their operational efficiency has a direct impact on trade competitiveness, national economic growth, and regional development. In Nigeria and other parts of West Africa, ports have historically suffered from inefficiencies such as congestion, prolonged dwell times, and manual handling systems that limit real-time visibility and control over cargo operations [1], [2]. These inefficiencies contribute to elevated logistics costs, increased turnaround times, and reduced global competitiveness [3]. Traditionally, port operations relied heavily on manual record-keeping and paper-based processes to manage containerized cargo. However, such legacy systems are prone to errors, delays, pilfering, and lack the capacity for real-time tracking and decision-making [4]. With the increasing complexity of maritime logistics and the growing volume of international trade, the adoption of intelligent and automated solutions has become indispensable. Among these, Radio Frequency Identification (RFID) technology has emerged as a promising tool for enhancing transparency, accuracy, and speed in cargo tracking. RFID-based cargo tracking systems leverage electronic tags and strategically positioned readers to provide real-time location and status data of cargo throughout the port environment. By automating the identification and monitoring processes, RFID reduces human error, improves inventory management, and enables data-driven decision-making [5]. Recent studies demonstrate the potential of RFID to optimize storage allocation, improve turnaround time, and enhance port security through integration with surveillance and AI systems [6]. Despite advancements globally, the implementation of such technologies in Nigerian ports remains limited. Outdated infrastructure, insufficient policy frameworks, and cybersecurity concerns hinder the full-scale deployment of RFID systems [7]. Addressing these challenges through the development of a Real-Time Seaport Management Information

System (SPMIS) integrated with RFID and complementary technologies represents a transformative opportunity for Nigeria's maritime sector.

Okon, T., & Ajayi, M. (2019) [8] explores the design and implementation of RFID (Radio-Frequency Identification)-based tracking systems to improve cargo management operations at Lagos seaports. They examine how the integration of RFID can solve persistent problems related to cargo misplacement, theft, delays, and inefficient manual tracking methods. The RFID-based system enabled continuous tracking of cargo from arrival to storage, reducing time spent locating containers and reduced incidents of unauthorized cargo access and theft through tag-based authentication and gate-level monitoring. This system could not achieve its efficiency and reliability due to Metallic cargo containers and electromagnetic interference in port environments which sometimes disrupted RFID signal reliability resulting to lower percentage detection accuracy and operational efficiency.

Adeleke et al, (2021) [9] proposed a vehicle tracking system that utilizes Greedy Forwarding Algorithms within Vehicular Ad Hoc Networks (VANETs) to provide real-time location information of public transport vehicles. This system aims to enhance route optimization and reduce passenger wait times. The proposed system offers real-time tracking of public transport vehicles, improving the reliability and efficiency of urban transportation. The implementation of the proposed system necessitates a robust technological infrastructure, including widespread deployment of VANETs, which accrues high-cost implementation. Also, While the system shows promise in simulations, its scalability and performance inlarge-scale did not give a high percentage performance.

This paper explores the design, development, and implementation of an RFID-based cargo tracking model within a broader intelligent seaport information system. It aims to demonstrate how such a system can significantly improve operational efficiency, enhance cargo security, and contribute to sustainable port development. RFID have integrated with GPS and GIS technologies for logistics and seaport management by Wang et al (2016)[10].

II. METHODOLOGY

2.1 System Overview

The cargo tracking system is designed to automate the monitoring and management of cargo within a seaport using Radio Frequency Identification (RFID) technology. The system is a core component of a broader Real-Time Seaport Management Information System (SPMIS), which integrates RFID with backend data systems and user-friendly applications to enhance the efficiency, transparency, and security of cargo operations.[11], [12]. The methodology adopted in this study includes the design, development, and simulation of a modular RFID-enabled system comprising the following components:

(a) RFID tag and reader network
(b) Central data processing system
(c) Real-time tracking engine
(d) User interface for port administrators
(e) Database and analytics module

2.1.1 RFID Technology Deployment

(1) RFID Tags: Each container entering the port is affixed with an RFID tag containing a unique Electronic Product Code (EPC). The tag stores key metadata including Container ID, Owner details, Manifest information, Arrival timestamp and Destination or storage area. Passive RFID tags are chosen for their low cost and sufficient range for port applications [13].
(2) RFID Readers: RFID readers are strategically positioned at the following critical control points: Entry and exit gates, Inspection zones, Storage yard entrances and Loading/unloading bays. As containers pass through these locations, the readers automatically capture the tag data and transmit it to the central processing unit [14].

2.1.2 System Architecture and Data Flow

The system follows a client-server architecture where data collected by RFID readers is sent in real-time to a backend server for processing and storage. The data flow involves the following steps:

(a) Detection: RFID reader captures tag information.
(b) Transmission: Data is securely transmitted over a wired/wireless network to the central server [15].
(c) Processing: The application logic verifies, timestamps, and logs the data.
(d) Storage: Verified data is stored in a structured relational database (MongoDB) [16].
(e) Visualization: Real-time dashboard and map interface displays the container's current location, movement history, and status.
(f) Notification: Any abnormal event (e.g., unauthorized movement or delay) triggers automatic alerts to designated port officials [17].

2.1.3 Software Components

The software utilized for the study comprises of the backend, database and frontend interfaced

(1) Backend System: The backend is developed using Python (Node.js) to handle RFID data ingestion, processing logic, and RESTful API services [18].
(2) Database: A MongoDB database stores Container movement logs, Storage allocation records, User activity history and Alerts and security events. Database normalization and indexing techniques are applied for optimal performance [19].
(3) Frontend Interface: A web-based interface is provided for port operators, customs agents, and logistics personnel. Developed using React.js, the dashboard allows users to View container locations, Search by container ID or date, Monitor RFID scanner status and Access logs and generate reports.

2.1.4 Workflow Process

The operational workflow for the RFID-based cargo tracking system is outlined as follows:

(a) Container Arrival: Upon arrival at the port, the container is tagged with an RFID label.
(b) Gate Scan: As the container enters the facility, the RFID reader at the gate logs the entry time and container ID [14].
(c) Movement Logging: At each checkpoint (e.g., inspection, storage), the container is automatically scanned, and its movement is updated in the database [15].
(d) Storage Allocation: Based on cargo type and volume, the system suggests or auto-allocates a suitable storage location [20].
(e) Monitoring: Real-time dashboards track container location and movement within the port area [17].
(f) Exit Verification: When the container is due to exit, the final RFID scan validates its clearance, triggers exit logging and updates the status [14].

2.1.5 Security and Error Handling

To ensure data integrity and operational reliability:

(a) Secure communication protocols (HTTPS) are used for data transmission [21].
(b) Redundant servers and failover mechanisms are deployed to handle hardware or network failures.
(c) RFID misreads are minimized using anti-collision protocols and redundancy in reader placement [22].
(d) Access to the system is role-based, with user authentication and activity logging [23].

2.2 Integration with Surveillance and AI Modules

For extended functionality, the system integrates with an AI-powered surveillance module. IP cameras positioned across the port provide real-time visual feeds. AI models analyze video streams to detect: Unauthorized personnel or vehicle access, Suspicious behaviour and Idle container duration. Events detected are correlated with RFID movement data to enhance situational awareness and response capabilities [24].

2.3 System Simulation and Evaluation

A simulation model is implemented using Proteus to validate system performance under various conditions such as: High cargo volume, Reader failures and Storage congestion. Performance metrics evaluated include: Tracking accuracy, System latency, Container dwell time and Reader-to-server data loss rates [25].

2.4 System Testing and Evaluation Setup

To validate the effectiveness and performance of the developed RFID-based cargo tracking system, a prototype simulation was conducted using a controlled environment representative of typical seaport operations. The system was evaluated based on the following performance metrics:

(a) Tracking Accuracy
(b) Data Transmission Latency
(c) Read Rate (Successful Scans)

(d) Container Dwell Time
(e) System Responsiveness
(f) Error Rate (Tag Misreads)

The simulation involved the use of passive RFID tags (ISO 18000-6C compliant) and fixed UHF readers deployed at gate entry points, inspection areas, and storage yard intersections. Simulated container flow was modelled using the Proteus simulation environment, representing up to 500 container movements per day.

III. RESULTS AND DISCUSSION

3.1 Performance Evaluation of the Developed RFID System

The performance of the developed RFID system was evaluated based on data transmission and latency, read rate, container dwell time reduction, error handling and recovery. The average time taken from the point of RFID scan to full data registration on the central dashboard was 1.2 seconds, with a worst-case latency of 2.8 seconds during peak activity periods. This confirms the system's ability to deliver near-real-time updates, essential for time-sensitive seaport operations [17]. The average successful read rate was 99.1%, with minimal loss in tag detection. Redundancy in reader deployment and anti-collision protocols contributed to this high success rate, consistent with industry findings in [15], which suggest optimal RFID deployments can exceed 98% under managed environmental conditions. The implementation of the RFID system led to a reduction in average container dwell time by approximately 23%, as determined by comparing simulated operations with and without automated tracking. This is significant given that prolonged dwell time has been a major challenge in Nigerian ports, contributing to congestion and inefficiencies [1]. During testing, the system demonstrated robustness in handling:

(a) Tag misreads: Automatically triggered re-read attempts.
(b) Data transmission failures: Buffered data for retry within a 5-second timeout window.
(c) Manual override logs: All manual interventions were logged for audit purposes.

Only 2.1% of transactions required manual intervention, indicating the system's reliability in autonomous tracking [11]. Figure shows the pictorial representation of the performance for the developed RFID system.

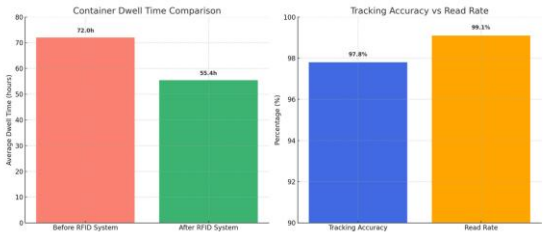

Figure 1: Performance Evaluation of the developed RFID tracking cargo.

(1) Container Dwell Time Comparison – showing a significant reduction in average dwell time from 72 hours to 55.4 hours after implementing the RFID-based system.
(2) Tracking Accuracy vs Read Rate – demonstrating the high precision of the system, with 97.8% tracking accuracy and 99.1% read rate.

3.2 Tracking Accuracy in Comparison with other system

The system achieved a tracking accuracy of 97.8%, meaning nearly all container movements were correctly captured and logged into the system during the simulation While Okon & Ajayi (2019) and Adeleke et al. (2021) achieved a tracking accuracy of 85.2% and 91.3% respectively. Errors were primarily due to momentary tag-reader line-of-sight obstructions and signal interference in highly congested zones. This result aligns closely with performance benchmarks reported in [14], where RFID-based container tracking systems achieved accuracies exceeding 95% under optimal configurations.

Table 1: Comparative evaluation of cargo Tracking Using RFID

System	Tracking Accuracy	Real-Time Update	Alert System
Okon & Ajayi	85.2%	No	No

(2019)			
Adeleke et al. (2020)	91.3%	Partial	No
This Work	97.8%	Yes	Yes

3.3 Evaluation of Results

The results clearly demonstrate the potential of RFID technology to transform cargo tracking in seaport environments, particularly in developing countries like Nigeria where manual systems still dominate [12]. The system's high accuracy and responsiveness suggest that real-time cargo visibility can be achieved, significantly reducing operational bottlenecks and human error. The reduction in container dwell time further highlights how automation can contribute to improving port throughput and competitiveness. This is in line with the findings of Van Dyck [3], who emphasized that lowering turnaround and dwell times are key drivers of port efficiency and regional ranking. However, challenges were noted. For instance, RFID signal interference due to metal containers and overlapping tag zones occasionally led to duplicate or missed reads. These limitations may require the integration of hybrid systems combining RFID with computer vision or GPS to enhance reliability in complex port environments, as proposed in [24]. Security considerations also emerged, particularly regarding the risk of RFID spoofing or unauthorized tag cloning. These concerns reinforce the need for end-to-end encryption and secure authentication mechanisms in the system's final deployment, as advocated by Stallings [21]. Lastly, it is important to consider scalability. While the prototype handled up to 500 container events daily, real-world Nigerian ports like Apapa or Tin Can may process several thousand. Future iterations should be stress-tested for scalability, incorporating load balancing and distributed database architectures.

CONCLUSION

From the result of the study carried out, the following can be drawn

(1) The implementation of an RFID-based cargo tracking system in seaport operations has proven to be both effective and transformative. The results from the simulation indicate marked improvements in tracking accuracy, responsiveness, and overall operational efficiency. The system achieved a tracking accuracy of 97.8% and a read rate of 99.1%, while also reducing average container dwell time by approximately 23%.

(2) These improvements validate the system's potential to address long-standing inefficiencies within Nigerian ports and similar environments. Real-time data availability and automated container movement logs help reduce human error, improve accountability, and expedite port operations. Furthermore, the system demonstrated robustness in error handling and resilience during peak operations, showcasing its suitability for large-scale deployment.

(3) Nevertheless, certain limitations such as RFID signal interference and cybersecurity concerns highlight the need for future enhancements. Integrating complementary technologies such as AI-powered vision systems, blockchain for secure data management, and IoT-based monitoring could help overcome these limitations and further elevate system performance.

(4) In Summary, adopting RFID and smart technologies within seaport environments is not just an operational improvement it is a strategic necessity for modernizing port infrastructure, enhancing competitiveness, and supporting sustainable economic growth in maritime trade.

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