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RESEARCH ON DESIGNING A SMART DEVICE SYSTEM APPLIED IN CONTAINER MANAGEMENT

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Abstract

In the context of rapidly growing container throughput in Vietnam—particularly at major seaports—the demand for efficient, secure, and transparent container transportation management has become increasingly critical. This study proposes a smart device system that integrates GPS, environmental sensors, and a cloud-based platform to enable real-time tracking and monitoring of container journeys. The proposed model holds promise for enhancing early risk detection, ensuring cargo security, and optimizing operations across the supply chain.

Keywords: Container Management; Smart Logistics; Sensors; GPS Tracking; Real-Time Monitoring; Supply Chain Security; Smart Devices.

1. INTRODUCTION

In the context of the continuously increasing volume of containerized cargo in Vietnam (Vietnam Maritime Administration, 2024), the need for effective journey monitoring and container security has become critical. Traditional methods have gradually revealed limitations in terms of real-time tracking, intrusion detection, and data integration. This study proposes the design of a smart device system that integrates environmental sensors, GPS tracking, and cloud-based connectivity to enable real-time container monitoring, anomaly alerts, and enhanced data security. The solution encompasses both hardware and software components, incorporating optimization algorithms to reduce processing time and improve operational efficiency in warehouse environments. The research aims to build a smart container management platform, contributing to the modernization of logistics in the industry 4.0 era.

2. LITERATURE REVIEW

Beyond its transport function, a container is a valuable asset that requires monitoring, maintenance, and efficient utilization. Poor container management can result in loss, damage, or delays, directly impacting the overall performance of the supply chain.

As a result, container management has evolved from a purely logistical task into a strategic component of modern logistics systems (Notteboom & Rodrigue, 2009).

H1: Container management has long been a strategic element..

The study is developed based on theories of logistics management, information systems, and the application of smart technologies in the supply chain (Christopher, 2016).

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It clarifies the structure and lifecycle of container management, including loading/unloading, customs clearance, and journey tracking. At the same time, the research analyzes the limitations of traditional sealing devices, such as the lack of tamper alerts, data latency, and poor system integration (Zhang & Zhang, 2020). However, according to UNCTAD (2022), only about 13–15% of global containers are equipped with GPS or IoT-enabled tracking systems.

H2: The current sealing devices still face limitations and fail to meet the evolving demands of the modern supply chain.

Therefore, this study proposes a solution that integrates IoT sensors, GPS tracking, real-time data transmission, and a cloud-based alert platform to enhance efficiency and security in smart container management. These solutions are becoming increasingly urgent as container throughput at Vietnamese ports continues to grow rapidly (Vietnam Maritime Administration, 2024).

H3: The research and development of new solutions are essential and urgent given the current situation in Vietnam.

3. RESEARCH METHODS

The study adopts a comprehensive and scientific approach by integrating various research methods, with the primary method being quantitative analysis. In addition, it also utilizes methods such as applied research, experimental design and prototyping, among others, to effectively achieve the proposed objectives, specifically:

To address practical issues in container management, this topic applies a combined methodology of applied research and research and development (R&D). The process begins with gathering information through an in-depth review of literature on IoT technologies, monitoring systems, logistics, and related standards. At the same time, it involves analyzing the current status of the actual container management process.

The development process is carried out using a prototyping model, which allows for early testing and refinement of core functions. Embedded programming is used to build the firmware for the device, ensuring accurate data collection and transmission from sensors. The management website system is developed using modern web technologies, providing an interface for monitoring, reporting, and alerting.

Finally, the data collected from both laboratory testing and field experiments are analyzed quantitatively (reliability, accuracy, performance) and qualitatively (user feedback, real-world observations).

This comprehensive evaluation process not only verifies the feasibility and effectiveness of the solution but also provides a basis for refining and improving the system, confirming the success of the close integration between technical design and practical validation in the research.

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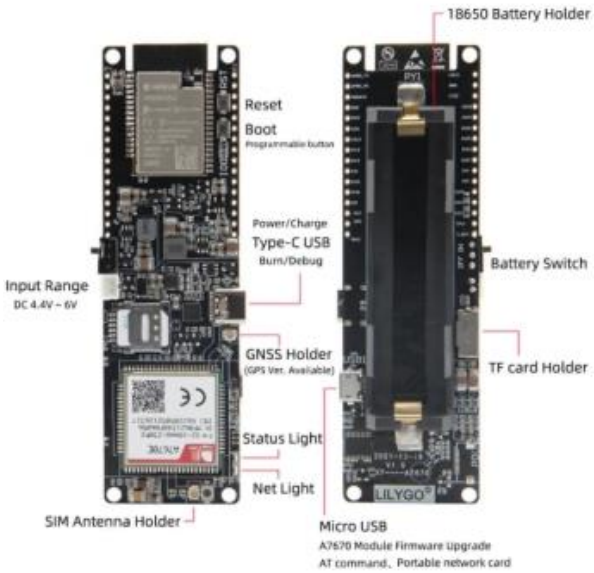
4. SOLUTION DESIGN

4.1.Smart device (CMSD)

4.1.1. Technical drawing.

- Overall dimensions: The length ranges from 105.59 mm to 110.54 mm; the width has two versions: 32.89 mm and 27.71 mm.
- Screw hole spacing: The four corners of the PCB have holes for mounting screws, with a distance from the edge of the board ranging from 2.29 mm to 2.67 mm.
- Component layout: central area; upper area; lower area.

4.1.2. Main structure



Front side: Includes the ESP32 module (central processor), Reset/Boot buttons, USB Type-C port, GNSS slot, LED indicator, antenna port, and SIM slot.

Back side: Contains a compartment for a 18650 battery, power switch, microSD card slot, Micro USB port, and the A7670 module (supports GSM, LTE, and IoT data).

4.1.3. Technical Specifications ESP32 and SIM7600CE

ESP32: Supports programming via USB, I2C, UART, SPI communication, power supply from 3.3V–5V.

SIM7600CE:

- Supports GSM, 3G, LTE Cat-4. Integrated GPS, Beidou, GLONASS positioning.
- Diverse communication (UART, USB, I2C), low power consumption, works well in environments from -40°C to 85°C.

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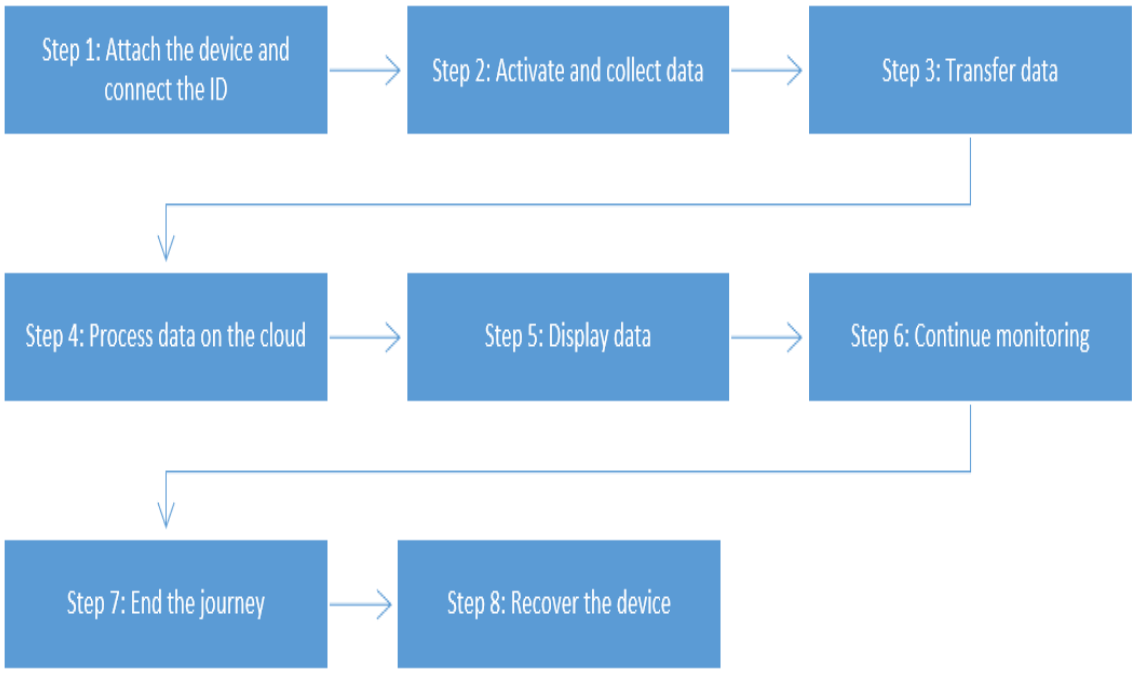
4.1.4. Website CT

A centralized management platform based on a web interface has been developed at the address https://tracking-demo.roz.io.vn/ to support real-time monitoring and management of containers. The main interface of this platform is a dashboard, providing managers and stakeholders with an instant view of operations. This dashboard includes: statistical cards displaying the number of entities being managed (containers, drivers, customers, orders);... The web platform continuously collects data from smart monitoring devices (CMSD) attached to the containers. Key functions include: real-time container location tracking on a digital map; reviewing and analyzing historical movement routes; monitoring the internal status and environmental conditions of the container (temperature, humidity, etc.) based on sensor data; managing and responding to automatically generated alerts; providing tools for generating reports to analyze performance. The system ensures that information is constantly updated, reflecting the latest status from the CMSD devices, thereby enabling proactive management and effective control of the container supply chain.

4.2. Flow diagram and how the system works



5. PERFORMANCE EVALUATION AND EXPERIMENTAL RESULTS

5.1. Experimental Context

To evaluate the CMSD system, a 3-month field trial was conducted with 5 devices on domestic road routes, in the context of operations similar to a mid-sized transport company in the North, with a comparison to previous traditional operational data.

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5.2. Kết quả Định lượng Chính

Testing shows very good performance of the system on important KPIs:

- **Data Transmission Reliability:** The success rate of data transmission from the device to the cloud is 99.6% via LTE mobile network.
- **Alert Performance:** The average delay from event detection to notification is very low (Geofence ~45s, Door Open ~30s, Temperature ~55s). The accuracy of the Door Open alert is 98.5% (True Positive).
- **Sensor Accuracy:** The average temperature error compared to the reference device is ±0.5°C.
- **Device & Battery Reliability:** Only one hardware failure was recorded throughout the trial (estimated high MTBF). The average battery life is 55 days with standard reporting frequency.
- **Security & Efficiency Impact:** A 75% reduction in security incidents (tampering, seal loss) on monitored containers compared to previous data. The need for manual status checks (calls/emails) decreased by over 85%.

5.3. Results

The synthesis of both quantitative and qualitative results confirms that the CMSD system is designed to operate effectively and reliably in real-world environments. The system provides accurate and timely location and status data, with a responsive alert mechanism and high hardware reliability. The solution has successfully demonstrated its ability to enhance cargo security, significantly improve supply chain visibility, and increase operational efficiency by reducing manual monitoring efforts, addressing the pressing needs of the logistics industry in Vietnam.

6. CONCLUSION

In the context of increasingly complex global supply chains that demand high immediacy, container management requires intelligent real-time monitoring solutions that go beyond traditional methods. This study proposes the design of a smart device system integrated with sensors, GPS tracking, and encrypted data transmission to enable location tracking, environmental monitoring, and abnormal interference detection throughout the container's transportation process. The system delivers practical value in preventing theft, cargo damage, and enhancing safety in container logistics. Theoretically, the research contributes to the cyber–physical systems (CPS) approach in container management, aligning with the trends of smart logistics and digital transformation in supply chains.

Moreover, the study emphasizes data security and integrity, addressing the growing risks of data breaches and cyberattacks in modern logistics. Overall, the research lays the groundwork for the development of future smart container management systems, aiming toward a transparent, efficient, and highly adaptive supply chain.

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