# LabVIEW-Based Automated System for Monitoring Real-Time Safety and Quality Conditions of Pharmaceutical Products in a Smart Container on a Ship

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Abstract: - This study presents the development and implementation of a LabVIEW-based automated monitoring and control system tailored for smart shipping containers used in the transportation of pharmaceutical products. The system is designed to maintain and regulate critical environmental parametersspecifically temperature, humidity, and light exposure-within containers to ensure the integrity, efficacy, and safety of sensitive medical cargo during maritime transit. Employing a modular and scalable architecture, the system integrates a suite of precision sensors including resistance temperature detectors (RTDs), capacitive humidity sensors, and ultraviolet-sensitive photocells. These sensors continuously collect environmental data, which is processed and visualized in real time through a userfriendly LabVIEW interface. Automated responses are triggered when predefined thresholds are exceeded: cooling/heating systems manage temperature excursions beyond 15-25 °C, humidifiers and dehumidifiers maintain relative humidity within 30-60%, and light sensors trigger alerts upon UV exposure. This architecture enables proactive environmental regulation without the need for human intervention, significantly reducing the risks associated with manual monitoring errors. The system not only enhances cargo safety and compliance with pharmaceutical storage standards but also demonstrates scalability for integration across multiple containers and logistics settings. Compared to traditional methods, the proposed solution offers superior precision, responsiveness, and traceability, thereby supporting Industry 4.0 goals within smart logistics. Its real-time SCADA-compatible interface and data logging capabilities allow for immediate anomaly detection and long-term analytics, reinforcing reliability and operational efficiency across the pharmaceutical cold chain.

Keywords:-- Smart Container, SCADA, Cargo Sensors, LabVIEW, Automated Electronic System, Product Quality

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# 1 Introduction

The evolution of smart containers represents a pivotal advancement within the broader trajectory of automation and digital transformation in logistics and supply chain management. Driven by the imperatives of operational efficiency, product integrity, and safety assurance in global commerce, the shipping industry has undergone substantial technological innovation in recent decades.

Containerization, introduced in the mid-20th century, fundamentally transformed global trade by standardizing cargo handling and transport. Despite its impact on logistics efficiency, conventional containers lacked the ability to monitor the internal condition of their contents. As international trade expanded and demand increased for the secure transport of high-value, sensitive, and perishable goods—such as pharmaceuticals and electronics these limitations became increasingly pronounced.

To overcome these challenges, the integration of sensor technologies and Internet of Things (IoT) connectivity into container infrastructure gave rise to smart containers. This transition was facilitated by advancements in wireless communication, embedded systems, and miniaturized sensors, particularly during the late 20th and early 21st centuries. Smart containers enable continuous critical parameters-including monitoring of temperature, humidity, pressure, and geolocationthereby providing real-time visibility into cargo conditions across the supply chain. The incorporation of Radio Frequency Identification

(RFID) and Global Positioning System (GPS) technologies in the early 2000s significantly enhanced the tracking and condition-monitoring capabilities of smart containers. Parallel developments in cloud computing, edge processing, and IoT platforms further supported scalable data acquisition, storage, analytics, and visualization. These capabilities enable data-driven decisionmaking, predictive analytics, and proactive maintenance strategies.

Since the early 2020s, smart container technologies have become integral to the Industry 4.0 paradigm, which emphasizes the convergence of physical systems with digital infrastructure. Major logistics and shipping enterprises have adopted these technologies to enhance transparency, reduce product losses, and meet stringent regulatory requirements, particularly in sectors such as food safety and pharmaceutical logistics.

Recent developments aim to address remaining challenges related to scalability, interoperability, energy efficiency, and cybersecurity. Innovations include blockchain-based secure data exchange, artificial intelligence (AI)-driven analytics, and ultra-low-power sensor networks, all of which reinforce the strategic role of smart containers in next-generation supply chain systems [1].

Concurrently, industrial automation is progressing toward increasingly integrated and intelligent architectures. A diverse array of technologies—such as the Industrial Internet of Things (IIoT), Supervisory Control and Data Acquisition (SCADA) systems, Programmable Logic Controllers (PLCs), Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP) systems, robotics, and AI-based applications—are being employed to optimize industrial processes.

The proliferation of IIoT is particularly notable, as it facilitates the deployment of smart devices capable of real-time data acquisition, processing, and communication. These systems support key objectives such as enhanced production efficiency, intelligent monitoring, and predictive maintenance, ultimately improving asset management and operational performance.

IoT-driven innovation is also reshaping interactions between humans and their environments, enabling greater adaptability and the deployment of interconnected infrastructure for future digital services. Although initially associated with consumer applications, IoT technologies have seen increasing adoption in industrial domains through tailored solutions.

SCADA systems play a critical role in industrial automation, offering real-time supervisory control and data acquisition capabilities. Often developed by vendors engaged in standardization efforts (e.g., through OPC—OLE for Process Control), SCADA systems establish reference architectures for integrating information technology into process control environments. They are already deployed in advanced research and industrial facilities, including experimental physics laboratories, where they manage essential subsystems such as power distribution, HVAC, and environmental monitoring [2].

Modern SCADA platforms have evolved significantly in terms of performance, scalability, and interoperability. Their current capabilities position them as viable alternatives to bespoke control systems, even in highly specialized and mission-critical applications.

# 2 Sensors Measurement Technology

## 2.1 Data Collection and Transmission

Smart containers are advanced shipping units enhanced with embedded technologies that extend their functionality far beyond that of conventional containers. These innovations are engineered to improve cargo visibility, security, and transportation efficiency, addressing critical demands in modern supply chain logistics [3].

A fundamental capability of smart containers lies in real-time tracking and environmental monitoring. Utilizing integrated Global Positioning System (GPS) modules, these containers enable continuous geolocation tracking throughout the transport cycle. Simultaneously, embedded sensors monitor key environmental variables—such as temperature, humidity, and internal pressure—ensuring compliance with transport conditions required for sensitive and perishable cargo.

To facilitate seamless communication and remote diagnostics, smart containers incorporate Internet of Things (IoT)-based communication systems. These platforms enable real-time data transmission to relevant stakeholders, including shipping operators, logistics coordinators, port authorities, and customs agencies. Such connectivity supports dynamic decision-making and improves supply chain responsiveness.

From a security perspective, smart containers can be equipped with electronic locks, intrusion detection mechanisms, and onboard surveillance systems, offering enhanced protection against unauthorized access and cargo tampering. These features are particularly critical in high-value or regulated shipments, where security breaches can result in significant financial or legal consequences.

Furthermore, smart containers support onboard data analytics, allowing operators to process and analyze collected telemetry to optimize route planning, enhance fleet utilization, and improve overall logistics efficiency. The availability of such actionable insights contributes to predictive maintenance and minimizes operational disruptions. Advanced condition monitoring capabilities further strengthen cargo integrity management. By capturing data on physical impacts such as shock, vibration, and tilt, these containers can detect potential threats to cargo safety in real time and trigger appropriate alerts or mitigation responses.

Lastly, automation technologies integrated into smart containers reduce dependency on manual operations. Automated features facilitate streamlined loading, unloading, and inspection procedures, accelerating turnaround times and improving overall throughput in port and intermodal operations.

Together, these features position smart containers as critical components of intelligent logistics systems, aligning with the goals of Industry 4.0 by enabling greater transparency, efficiency, and reliability in global trade operations.

## 2.2 Sensors Categorization

This study investigates the deployment of sensor technologies to monitor and maintain the safety and quality of environmental conditions within smart containers. These sensors continuously collect data, which is transmitted to a central processing unit typically a microcontroller or embedded computing system—that autonomously executes control actions to preserve optimal internal conditions. This section presents a classification of the primary sensor types utilized in container environments and outlines their respective functions and material compositions [4].

Temperature sensors, such as thermistors, resistance temperature detectors (RTDs), and thermocouples, are critical for monitoring thermal conditions in cargo. These sensors are fabricated using various materials: thermistors typically employ siliconbased semiconductors, RTDs utilize metals like platinum due to their stable resistive properties, and thermocouples are constructed from infraredsensitive materials to detect radiant heat. These devices are essential for maintaining product integrity in temperature-sensitive sectors such as food logistics, pharmaceuticals, and precision manufacturing.

Humidity sensors measure the relative moisture content in the air or surrounding materials, supporting environmental control in applications such as cold chain logistics, climate-regulated storage, and electronic component protection. These sensors are generally based on hygroscopic materials—such as polymers or ceramics—that absorb and release water vapor in response to changes in ambient humidity. Pressure sensors are employed to detect variations in gaseous or liquid pressure, enabling the identification of leaks, overpressure conditions, and system malfunctions in sealed containers or fluid handling systems. MEMS (Micro-Electromechanical Systems) pressure sensors commonly utilize silicon substrates, although ceramics, metallic films, and polymers are also used depending on the target application and required sensitivity. Vibration sensors are essential for structural health monitoring and transportation safety. These sensors detect mechanical oscillations using piezoelectric materials like quartz or lead zirconate titanate (PZT), which generate an electric charge under dynamic stress. Vibration analysis helps in preventive maintenance and the early detection of handling-induced mechanical damage. Accelerometers measure linear or angular acceleration and are critical in detecting impact events, assessing motion profiles, and monitoring equipment behavior. MEMS accelerometers typically comprise silicon-based sensing elements, including suspended masses or cantilever beams, which respond to inertial forces. Gas sensors enable the detection of specific gas concentrations within containers, ensuring compliance with safety and environmental regulations. These sensors employ technologies such as metal-oxide semiconductor sensing, electrochemical cells, or infrared absorption to identify gases like CO2, O2, NH3, or volatile organic compounds (VOCs), based on the target chemical species. Imaging sensors (i.e., industrial cameras) provide visual data for cargo inspection, equipment monitoring, and quality control.

These systems utilize CMOS (Complementary Metal-Oxide Semiconductor) or CCD (Charge-Coupled Device) image sensors, built from layered silicon and metal oxides, to convert optical signals into digital images. RFID (Radio Frequency Identification) sensors are employed for non-contact object identification and tracking. RFID systems consist of a tag—comprising a microchip and an antenna—and a reader. The microchip is typically fabricated from silicon, while the antenna is constructed using conductive materials such as copper or aluminum. These sensors are widely implemented in asset tracking, supply chain visibility, and anti-counterfeiting applications.

Load cells and digital scales are utilized to measure the mass or weight of container contents. These devices commonly incorporate strain gauges made from metallic or semiconductor materials, which exhibit changes in electrical resistance under mechanical deformation. They are vital for verifying payload accuracy and preventing overloading.

Proximity sensors detect the presence or movement of nearby objects without direct physical contact. Common types include inductive sensors (utilizing magnetic coils), capacitive sensors (featuring electrode arrays), and optical sensors (comprising light emitters such as LEDs and photodetectors). These devices are widely applied in container automation systems, robotic handling, and safety interlocks.pH sensors monitor the hydrogen ion concentration in liquid samples, providing critical insights into the acidity or alkalinity of substances. These sensors typically consist of a glass electrode that generates a voltage in response to the H<sup>+</sup> ion activity in solution. Applications include water quality monitoring, food production, and chemical processing.

Magnetic sensors, such as Hall effect sensors, are designed to detect magnetic field variations. They are fabricated using semiconductor materials like gallium arsenide or indium antimonide and are used in position sensing, motion tracking, and switch activation in industrial systems.

Photocells, or light-dependent resistors (LDRs), are used to quantify light intensity for applications such as ambient lighting control and quality inspection. Constructed from photoconductive materials, these sensors alter their electrical resistance based on the incident light levels.

Together, these sensors form the foundation of intelligent monitoring systems within smart containers, enabling automated decision-making, enhanced operational safety, and improved supply chain efficiency.

# **3** System Design and Architecture

Pharmaceutical products are highly sensitive to environmental conditions during transportation, necessitating the use of smart containers equipped with advanced monitoring and control systems. These containers must integrate high-precision sensors to maintain optimal storage conditions and ensure product integrity across the supply chain. The monitoring system must continuously evaluate key parameters such as temperature, humidity, and light exposure, which are critical to preserving the quality, efficacy, and safety of pharmaceutical goods.

Temperature monitoring is achieved through the integration of high-accuracy sensors such as resistance temperature detectors (RTDs) or digital temperature sensors. These devices provide precise readings and rapid response to thermal changes, ensuring that pharmaceuticals remain within the recommended storage range, typically between 15°C and 25°C. Exposure to temperatures outside this range can compromise the chemical stability of medications and reduce their therapeutic effectiveness.

Humidity control is equally essential, especially for moisture-sensitive compounds. The smart container employs capacitive or resistive humidity sensors to monitor relative humidity within the enclosure. Excessive moisture can cause degradation, clumping, or microbial contamination of certain medications. Therefore, the system is designed to activate humidification mechanisms when humidity falls below 30%, and to initiate dehumidification when levels exceed 60%. These thresholds are maintained through a closed-loop feedback system that adjusts environmental conditions in real-time based on sensor input.

Light exposure monitoring is implemented using photocells or UV-sensitive photodiodes capable of detecting ultraviolet radiation within the container. Some pharmaceuticals are vulnerable to photochemical reactions that can occur under prolonged exposure to UV light, leading to chemical breakdown and reduced potency. The sensors measure and report ambient light levels, enabling protective measures such as alarms or automated shielding to be deployed when light exposure exceeds safe thresholds.

To implement this intelligent monitoring system, it is first necessary to define the system requirements, which include identifying key environmental variables, selecting appropriate sensor types, and specifying parameters for data acquisition, control, and visualization. In this context, the LabVIEW software environment is utilized for programming the control logic, processing sensor inputs, and providing a user interface for system configuration and monitoring.

The system architecture is based on maintaining three core parameters for pharmaceutical safety: temperature between 15°C and 25°C, humidity ranging from 30% to 60%, and minimal or no exposure to UV radiation. A functional block diagram represents the interaction of sensors, controllers, and actuators responsible for managing these environmental factors. It includes subsystems for heating, cooling, humidification, and dehumidification, all governed by real-time sensor feedback.

Temperature regulation operates by comparing the measured temperature with the defined thresholds. If the temperature falls below 15°C, the heating system is activated, whereas a temperature above

25°C triggers the cooling system. Similarly, the humidity control system uses two threshold values—30% for low humidity and 60% for high humidity. If the humidity drops below 30%, the humidifier is turned on; if it rises above 60%, the dehumidifier is activated. Light detection operates through a sensor that activates a blinking indicator when exposure is detected, alerting the system and the user to potential risks. Each of these systems heating, cooling, humidification, and dehumidification is controlled through logic conditions that activate or deactivate them based on real-time sensor data. The system also includes a stop button that provides full shutdown functionality. The LabVIEW front panel interface is designed to facilitate real-time monitoring and control of the environmental conditions inside the smart container. It provides visual indicators and numeric displays for each parameter. For temperature monitoring, a vertical thermometer with a range from 0°C to 30°C shows the current value 26°C in this instance. Adjacent indicators labeled "LOW" and "HIGH" signal whether the current temperature is outside the predefined limits. When the temperature exceeds 25°C, the cooling system is automatically engaged, while the heating system remains inactive unless the temperature drops below 15°C. A corresponding temperature chart displays the temporal variation in temperature, with markers indicating significant changes such as the recent increase to 26°C.

Humidity is represented on a vertical scale from 0% to 100%, with the current reading displayed numerically. In this scenario, the system registers a humidity level of 0%, activating the "LOW" status indicator and triggering the humidifier. A graphical plot logs humidity trends over time to support historical analysis and fault detection.

Light exposure is monitored via a sun-shaped icon, which changes color when light is detected. In the current case, a yellow light is shown, and the alarm is triggered to indicate exposure to sunlight, signaling the risk of UV-induced degradation. This immediate feedback allows operators to take corrective actions promptly.

Overall, the integration of these environmental monitoring and control features within the smart container ensures that pharmaceutical products are transported under strictly controlled conditions. By leveraging sensor technologies and a programmable LabVIEW interface, the system enables continuous tracking and real-time adjustment of temperature, humidity, and light exposure, thereby ensuring compliance with pharmaceutical storage standards and enhancing product reliability during transit.



Fig.1: Block Diagram of System



Fig.2: Front Panel of System

# 4 Conclusion

The proposed smart container monitoring and control system offers significant advancements over conventional manual methods and existing automated solutions. By leveraging real-time data acquisition, high-precision sensing, and intelligent control mechanisms, the system enhances the scalability, and efficiency reliability. of environmental monitoring for sensitive goods such as pharmaceuticals and perishable products. One of the most critical improvements is the marked increase in accuracy and reliability. Manual monitoring processes are inherently susceptible to human error, inconsistencies in data recording, and subjective interpretation, all of which can compromise product safety. In contrast, the system continuously automated captures environmental parameters-such as temperature, humidity, and light exposure-using calibrated, high-accuracy sensors. These sensors enable autonomous decision-making processes, thereby reducing human involvement and minimizing the risk of error-induced product degradation.

The system also significantly improves operational efficiency. Manual inspection routines are laborintensive and time-consuming, often requiring substantial human resources to conduct routine This traditional checks. approach delays responsiveness to critical environmental fluctuations. The automated system, by continuously analyzing environmental data, enables proactive intervention and dramatically reduces the time and labor costs associated with manual monitoring, ultimately ensuring timely responses to deviations from predefined safety thresholds.

Scalability and uniformity represent additional engineering advantages of the developed system. Human-centric monitoring systems face intrinsic limitations in terms of scalability due to cognitive and procedural inconsistencies among operators. These limitations become increasingly pronounced in large-scale or complex logistics networks. The automated system, by contrast, ensures consistent performance across all monitored units, applying standardized protocols irrespective of the scale of deployment. This uniformity is particularly beneficial in sectors such as pharmaceutical logistics and cold-chain transportation, where regulatory compliance and quality assurance are paramount.

Perhaps the most transformative aspect of the system is its provision of real-time monitoring capabilities. Traditional methods, reliant on periodic inspections, leave temporal gaps during which environmental deviations may go undetected. These interruptions can compromise the integrity of sensitive products. The smart container system eliminates this vulnerability by enabling continuous monitoring and immediate anomaly detection. As a corrective actions can be result, initiated instantaneously, thus preserving product quality and ensuring adherence to stringent safety standards.

In summary, the integration of high-precision sensors, autonomous control algorithms, and realtime data visualization within the smart container framework establishes a robust, scalable, and efficient monitoring solution. It ensures optimal environmental conditions throughout the transportation and storage process, offering a significant leap forward in safeguarding the quality and safety of sensitive goods across complex supply chains.

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The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution

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#### **Conflict of Interest**

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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