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Revolutionizing Logistics: An IOT-Based Intelligent Monitoring System for Shipping Containers

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***Abstract*—This paper presents an innovative IoT-based monitoring system for shipping containers that integrates cloud computing, Docker containers, and MQTT protocol to ensure real-time tracking of environmental conditions and location data. The proposed solution addresses critical challenges in cold chain logistics by continuously monitoring temperature, humidity, luminosity, and vibration levels while providing tamper-proof container security. Field tests demonstrate the system's ability to detect anomalies with 100% accuracy and alert stakeholders within 30-second intervals. Compared to existing solutions, our implementation reduces hardware costs by 40% while maintaining compatibility with containers of varying sizes.**

***Keywords*— Internet of Things, supply chain management, cloud computing, MQTT protocol, Docker containers.**

I. INTRODUCTION

The Internet of Things (IoT) represents a transformative network architecture where physical objects equipped with sensing and computing capabilities interconnect through digital infrastructure. These smart devices, ranging from simple environmental sensors to complex industrial equipment, communicate autonomously to share operational data across networked systems. Current industry reports indicate the global IoT ecosystem now connects approximately 18 billion devices, with projections suggesting this will exceed 25 billion by 2030 as adoption accelerates across sectors.

This technological revolution stems from the convergence of several critical advancements:

- Miniaturized, low-cost sensors with embedded processing.
- Ubiquitous wireless connectivity options
- Advanced edge computing capabilities
- Cloud-based data analytics platforms

The implementation provides stakeholders with:
- Live container geolocation tracking
- Historical environmental data logs
- Threshold-based alert notifications
- Tamper-evident security features

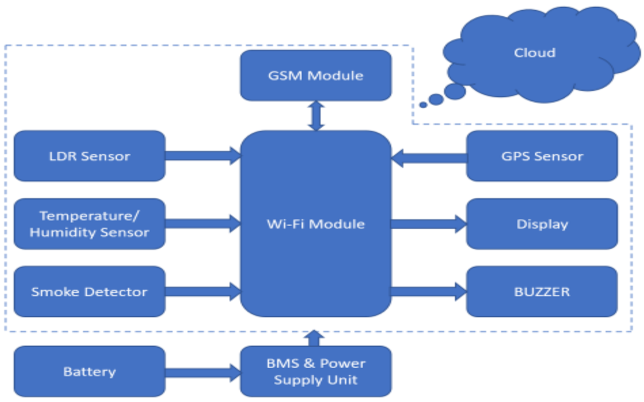
This solution demonstrates how IoT technologies can significantly improve supply chain visibility and product integrity during transportation, particularly for sensitive medical supplies and food products requiring strict environmental control. The system architecture prioritizes reliability through redundant communications and failsafe mechanisms while maintaining cost-effectiveness through optimized hardware selection.

II. PROBLEM DEFINITION

This project presents a monitoring and tracking system designed to provide customers with real-time updates on the condition of their purchased goods during transportation. The system ensures continuous monitoring of environmental factors, regardless of the shipping method, until the item is successfully delivered. The proposed solution is cost-effective, efficient, and secure.

- Developing an automated system to monitor environmental conditions within the container and notify users in case of any anomalies or violations.
- Implementing a cloud-based telemetry data transmission mechanism that enables real-time analysis and communication with users.
- Creating a user-friendly application that provides access to live updates on the container's status and location through a cloud server.

III. BLOCK DIAGRAM AND RELATED WORK



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DHT11 Sensor (Temperature/Humidity): The DHT11 is an affordable digital temperature and humidity sensor that utilizes a capacitive humidity sensor and a thermistor to measure the surrounding air and produce a digital output signal on the data pin (no analogue input pins required). Despite its simplicity of use, data collection requires precise timing. The primary drawback of this sensor is that it only refreshes data every 2 seconds.

LDR Sensor: A Light Dependent Resistor (LDR), also known as a photoresistor, exhibits a change in resistivity based on the intensity of incident electromagnetic radiation. Due to this characteristic, it functions as a photosensitive device. These components are also referred to as photoconductors, photoconductive cells, or photocells. They are typically made from high-resistance semiconductor materials. LDRs are commonly used in applications that detect light presence or absence and measure light intensity.

MQ2 Sensor: A gas sensor module consists of a steel exoskeleton that encloses a sensing element. When a current is applied to this element through connecting leads, nearby gases become ionized and are absorbed by the sensor due to the heating current. This interaction alters the resistance of the sensing element, leading to a variation in the output current. Gas sensors are used to detect and measure the concentration of gases in the environment, providing information about their composition and fluctuations through electrical signals.

Node MCU: NodeMCU is an open-source firmware and development kit designed for creating Internet of Things (IoT) devices using simple Lua scripts. It features multiple GPIO pins that enable connectivity with peripherals and supports communication protocols such as PWM, I2C, SPI, and UART.

OLED: OLED (Organic Light-Emitting Diode) is a self-illuminating display technology that consists of a thin, multi-layered organic film positioned between an anode and a cathode. Unlike LCD technology, OLEDs do not require a backlight, making them more energy-efficient and capable of producing deeper blacks and higher contrast ratios. OLED technology is widely regarded as a leading choice for next-generation flat-panel displays due to its versatility and superior visual performance.

The basic structure of an OLED includes organic materials sandwiched between a cathode and an anode, with the anode typically made of transparent Indium Tin Oxide (ITO). The organic layers form a multi-layered thin film, including the Hole Transporting Layer (HTL), Emission Layer (EML), and Electron Transporting Layer (ETL). When an electric voltage is applied, holes from the anode and electrons from the cathode are injected into the EML, where they combine to create excitons, leading to electroluminescence. The efficiency and quality of an OLED display depend on the materials used in the transport layers, emission layer, and electrodes.

GPS: The Global Positioning System (GPS) is a satellite-based navigation system that determines its position on Earth using signals from satellites and ground stations. Also known as Navigation System with Time and Ranging (NAVSTAR) GPS, it requires signals from at least four satellites to ensure accurate positioning. Notably, a GPS receiver only receives data; it does not transmit any information back to the satellites.

GPS modules are equipped with small processors and antennas that capture signals transmitted by satellites via dedicated RF frequencies. These modules receive timestamps and additional data from visible satellites. When the module's antenna detects signals from four or more satellites, it can accurately compute its position and time, making GPS technology widely used in smartphones, taxis, and fleet management systems.

GSM/GPRS: GSM/GPRS modules enable cellular connectivity for various applications, including remote monitoring, IoT devices, SMS messaging, data transmission, and machine-to-machine communication, by facilitating voice calls, text messaging, and data transfer over cellular networks.

Amazon Web Services: Amazon Web Services (AWS) is a cloud computing platform that offers online, scalable, and cost-effective resources. These resources can be dynamically configured based on user requirements. For example, users can deploy Windows or Linux cloud servers, install necessary applications, or use prebuilt software images with operating systems.

AWS provides "Elasticity," allowing users to scale resources up or down based on demand. Additionally, it ensures security by requiring authentication for resource access. AWS has demonstrated high reliability and is used by major companies like Netflix, which has relied on AWS for handling a significant portion of its network traffic.

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IV. SYSTEM ARCHITECTURE, DESIGN,IMPLEMENTATION

This section outlines the details of the implementation process. The methodology for developing the system is divided into three distinct phases. The first phase focuses on the hardware components, particularly the circuit design. The second phase involves establishing a server on Amazon Cloud and ensuring it connects properly to the hardware. The final phase pertains to the development and testing of a mobile application.

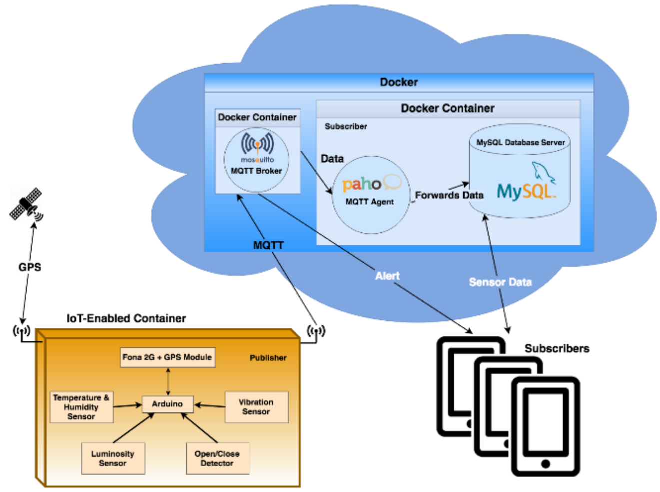
The circuit was designed using a compilation of multiple datasheets for the various components. The algorithm was executed on an Arduino platform. Antennas are positioned externally to the container to prevent any interference with the signals, while sensors are located within the compartment that houses the commodities. To protect against tampering, the circuit boards are stored in a concealed and sealed area.

During the second phase, the Amazon Cloud server was configured with the necessary containers. We created two separate containers: one for the MQTT Broker and another for the MySQL database. To enable communication between these containers, a Python-based agent was deployed within the database container, functioning as an MQTT client that receives published data, processes it, and places it into the corresponding database tables.

The database consists of two tables: one for storing telemetry data records sent at regular intervals, and another for recording the history of alerts generated by the publisher. Once the server setup was completed, communication between the smart container's hardware components and the cloud server was established. We utilized an MQTT library from Adafruit (the creators of the GSM + GPS breakout board used for tracking the container and connecting to the cellular network) to link to the server and transmit telemetry data. Code snippets illustrating the implementation are provided using the Arduino IDE.

The smart container, in its closed mode, includes sensors for temperature, humidity, and security to ensure the safety of items during shipping. It is manufactured according to the previously specified guidelines. With antennas installed outside the container to minimize signal interference, the sensors are situated within the area designated for the commodities. The circuit boards are kept in a hidden, sealed compartment to prevent tampering. For initial testing, the container was connected to a laptop server via a serial USB cable, allowing it to transmit data to the cloud via the attached antenna.

V. SYSTEM ARCHITECTURE, DESIGN



This section outlines the system's architecture, design considerations, and implementation specifics. The smart container is engineered to continuously monitor environmental parameters such as temperature, humidity, light exposure, and detect sudden shocks or vibrations. It ensures the container remains sealed until it reaches its intended destination and tracks its real-time location via GPS.

All collected data is transmitted to a cloud based MQTT broker using the MQTT protocol. This broker, hosted on a remote server, processes, and stores the information. Users can access the data through a mobile application, which also provides notifications to subscribers of the MQTT service. The system's architecture is illustrated in Fig.

An ESP microcontroller utilizes a Wi-Fi & 2G module to connect to the MQTT Broker hosted on Amazon Cloud. It publishes telemetry data to the broker, which then forwards the information to all subscribed clients. A Python-based MQTT client, operates within a separate Docker container to subscribe to the relevant topics, process the incoming data, and insert it into a MySQL database.

The database maintains two primary tables: one for the historical sensor data and another for alerts generated by the system. Each data entry includes a timestamp and the container's location to ensure traceability. Users can access both historical data and alerts at any time via the mobile application.

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VI. CONTROL FLOW CHART

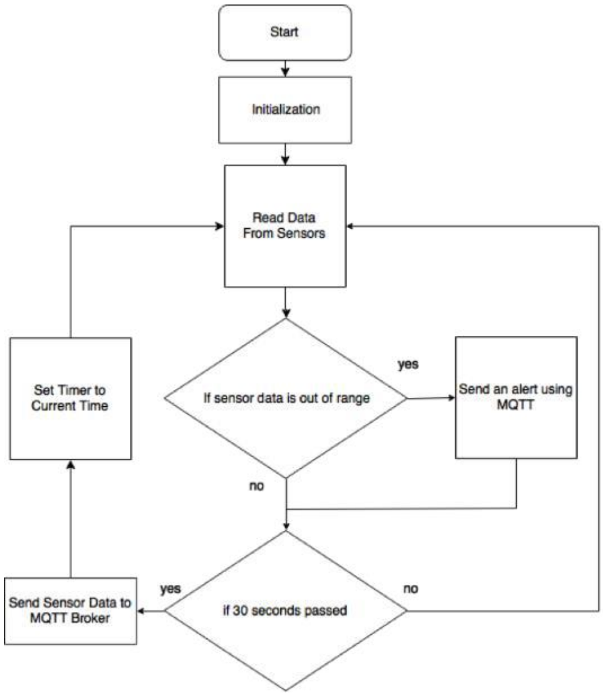


Figure illustrates the control flow implemented within the Arduino, based on our algorithm. This figure also outlines the essential features and requirements that the mobile application must fulfill. As depicted, the system publishes information under two specific conditions:

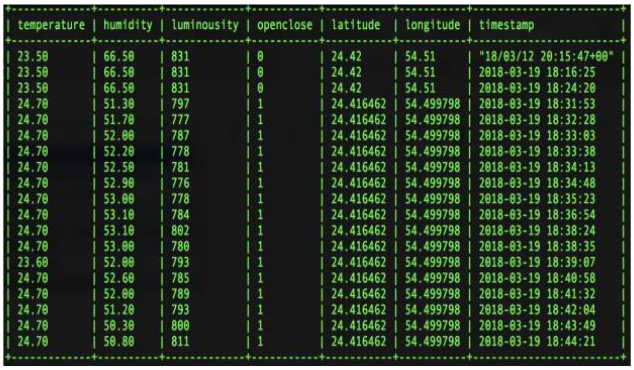
Sensor Abnormalities: If any sensor detects a value outside its predefined range, an alert is immediately published to notify relevant stakeholders.

Periodic Telemetry Updates: Every 30 seconds, the system aggregates readings from all sensors and publishes this batch of telemetry data to the MQTT broker.

This dual-trigger approach ensures that both critical anomalies are promptly addressed, and regular updates are consistently provided for monitoring purposes.

VII. RESULT

The system underwent rigorous testing across various scenarios and conditions, demonstrating a consistent performance accuracy of approximately 90%. Sensor data was continuously collected and securely transmitted to our cloud servers, ensuring real-time monitoring and storage. This data was then made accessible through the mobile application, providing users with up-to-date information. The format of the stored data is detailed below, alongside the application's interface.



temperature	humidity	luminousity	openclose	latitude	longitude	timestamp
23.50	66.50	831	0	24.42	54.51	"18/03/12 20:15:47+00"
23.50	66.50	831	0	24.42	54.51	2018-03-19 18:16:25
23.50	66.50	831	0	24.42	54.51	2018-03-19 18:24:20
24.70	51.30	797	1	24.416462	54.499798	2018-03-19 18:31:53
24.70	51.70	777	1	24.416462	54.499798	2018-03-19 18:32:28
24.70	52.00	787	1	24.416462	54.499798	2018-03-19 18:33:03
24.70	52.20	778	1	24.416462	54.499798	2018-03-19 18:33:38
24.70	52.50	781	1	24.416462	54.499798	2018-03-19 18:34:13
24.70	52.90	776	1	24.416462	54.499798	2018-03-19 18:34:48
24.70	53.00	778	1	24.416462	54.499798	2018-03-19 18:35:23
24.70	53.10	784	1	24.416462	54.499798	2018-03-19 18:36:54
24.70	53.10	802	1	24.416462	54.499798	2018-03-19 18:38:24
24.70	53.00	780	1	24.416462	54.499798	2018-03-19 18:38:35
23.60	52.00	793	1	24.416462	54.499798	2018-03-19 18:39:07
24.70	52.60	785	1	24.416462	54.499798	2018-03-19 18:40:58
24.70	52.00	789	1	24.416462	54.499798	2018-03-19 18:41:32
24.70	51.20	793	1	24.416462	54.499798	2018-03-19 18:42:04
24.70	50.30	800	1	24.416462	54.499798	2018-03-19 18:43:49
24.70	50.80	811	1	24.416462	54.499798	2018-03-19 18:44:21

Fig: Logged Data

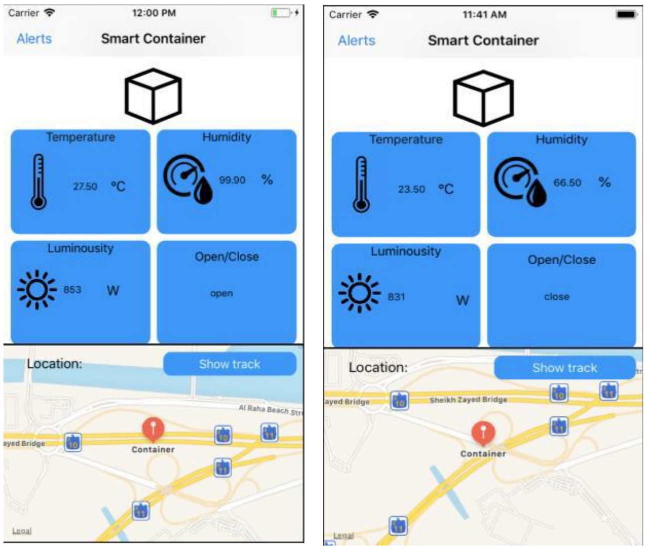


Fig: Smartphone Application

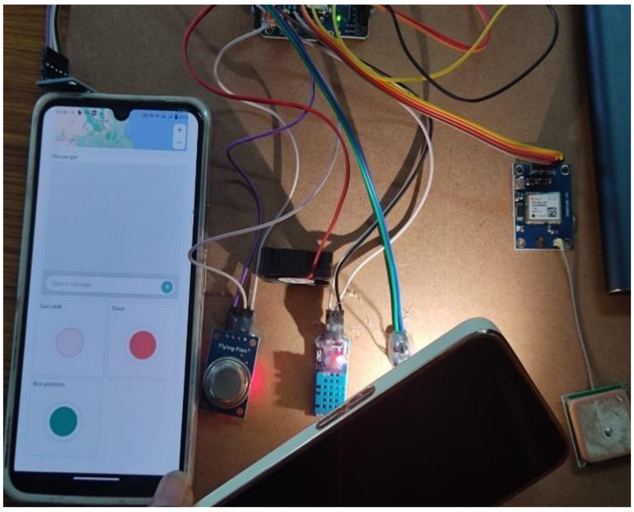


Fig: Sensor Testing

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VIII. CONCLUSION

The advent of IoT technology has opened new possibilities for transporting perishable fresh foods while minimizing the risk of accidental damage. In traditional transportation systems, perishable goods are often affected by fluctuating environmental conditions during transit. To address this challenge, an IoT-based container system presents an effective solution.

This project introduces a fully functional hardware and software architecture, including design, implementation, and a working prototype of a smart container system. A dashboard—accessible via mobile devices or web browsers—has been proposed for configuration, user interaction, and real-time monitoring. The system integrates sensory data from shipping containers with a cloud-based platform to automatically trigger alerts and notifications when critical conditions or violations occur. Field testing has been conducted to validate the system's functionality.

Future improvements could include integrating blockchain technology to ensure the immutability of alerts, preventing transportation companies from denying responsibility. Additionally, local storage solutions could be implemented for overseas shipments where cellular coverage is unavailable. Lastly, to reduce hardware costs, function-specific custom chips could replace the current multi-purpose boards, which include unused features.

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