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IoT Based Intelligent Cold Storage Monitoring for Food and Medicine

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Abstract:

Cold storage is an essential component in the preservation of perishable food products and temperature-sensitive medicines. Maintaining a consistent and suitable environment is crucial for ensuring the longevity and safety of these items, as fluctuations in temperature and humidity can lead to spoilage, microbial growth, chemical degradation, and significant economic losses. Traditional cold storage systems often rely on manual supervision and conventional thermostatic controls, which are insufficient for addressing sudden environmental changes. This paper presents an Autonomous IoT-Based Intelligent Cold Storage Monitoring System designed to continuously monitor and control environmental conditions. The proposed system integrates temperature, humidity, and gas sensors (DS18B20/LM35, MQ-series) with a PIC16F877A microcontroller and an ESP8266 Wi-Fi module. It implements automated corrective mechanisms via water sprayers, heating elements, and ventilation. Through cloud integration, the system offers real-time remote tracking, immediate alert notifications, and continuous data logging. Experimental results demonstrate a 30% reduction in energy consumption and high reliability in predicting and preventing spoilage, proving its efficacy as a scalable solution for food warehouses, pharmaceutical storage, and hospitals.

Keywords — **IoT, Cold Storage, PIC16F877A, ESP8266, Food Safety, Remote Monitoring, Predictive Analytics.**

I. INTRODUCTION

Cold storage is an essential component in the preservation of perishable food products and temperature-sensitive medicines. Maintaining a consistent and suitable environment is crucial for ensuring the longevity and safety of these items. Fluctuations in temperature and humidity can lead to spoilage, microbial growth, chemical degradation, and significant economic losses.

Traditional cold storage systems often rely on manual supervision and conventional thermostatic controls, which are insufficient for addressing sudden environmental changes. For instance, a sudden rise in temperature due to equipment malfunction or power disruption can cause irreversible damage to stored food or pharmaceuticals, while excessive humidity can accelerate spoilage, promote mold growth, and degrade medicines. Similarly, insufficient humidity may lead to drying, shrinkage, or loss of quality in food items, compromising their market value and safety.

In recent years, advances in Internet of Things (IoT) technologies have made it possible to overcome these limitations through continuous monitoring, real-time data collection, and intelligent automated control. An IoT-based intelligent cold storage system provides a proactive approach to storage management, ensuring that any environmental deviations are detected immediately and corrected automatically, reducing dependence on manual oversight and minimizing the risk of loss.

A. Project Overview

The proposed system integrates multiple sensors, actuators, and a microcontroller to form a fully automated and intelligent monitoring setup. Temperature sensors continuously measure the internal temperature of the storage area. These sensors are capable of detecting even minor deviations from the safe range, enabling timely corrective action. Gas sensors detect the presence of harmful gases or foul odors that may result from food spoilage or chemical reactions in pharmaceuticals.

The microcontroller serves as the central processing unit, receiving real-time data from all sensors, analyzing it, and triggering actuators to maintain optimal storage conditions. Actuators include water sprayers, heating elements, or lights, which are activated to correct temperature deviations, while humidifiers or dehumidifiers maintain the desired moisture levels.

The system is further enhanced through IoT integration, which allows sensor data to be transmitted to cloud platforms in real time using protocols such as MQTT or HTTP. This enables remote monitoring through mobile applications or web-based dashboards.

B. Objectives

- To monitor temperature and humidity in cold storage using IoT sensors.
- To maintain proper storage conditions for food and medicines.
- To automatically control cooling and heating systems.
- To detect harmful gases and excess moisture early.
- To send real-time alerts to users through mobile or web applications.
- To enable remote monitoring and reduce manual supervision.

II. LITERATURE SURVEY

In industries including food, medicine, and agriculture, the preservation of perishable items throughout storage and transit is a major concern. Nearly 20% of perishable commodities are lost worldwide as a result of handling and environmental mismanagement.

1. IoT Based Real Time Environmental Monitoring System for Cold Chain Logistics: Lingeswari et al. (2025) focus on improving the efficiency and reliabil- ity of cold chain logistics through the use of IoT technol- ogy. The proposed system utilizes sensors to continuously monitor environmental parameters and transmit data to a cloud-based platform. Abnormal conditions generate alerts, allowing immediate corrective action. The study highlights that IoT-based monitoring systems significantly reduce the risk of spoilage.

2. Smart Storage Solutions for Cold Chain: Integrating Technology for Vaccine Preservation: Sona Teresa Jossy et al. (2024) propose a smart storage solution using IoT for cold chain vaccine preservation. Vaccines are highly sensitive to temperature variations, and even small changes can render them unusable. The system continuously monitors parameters inside vaccine storage units and sends data to a centralized platform. Results show improved operational efficiency with real-time alerts for low stock and expiring vaccines.

3. Deep Learning Based Cold Chain Distribution Model with Blockchain: M. Siva Ramkumar et al. (2023) highlight that transportation and storage regulations are very stringent in the pharmaceutical cold chain. They propose a Deep Learning based Cold Chain Distribution Model (DL-CCDM) utilizing blockchain and IoT. Deep learning algorithms analyze large amounts of sensor data to predict potential risks, while blockchain securely stores the data, ensuring transparency, traceability, and protection against manipulation.

4. Design of a Dynamic Monitoring System for Groundwater in the High Cold Zone Based on IoT: (2022) China's high cold zone has a severe environment. This study proposes an online monitoring system with significant environmental adaptability. The sensor's temperature adjustment method was explored, with correctness demonstrated using accuracy tests. It highlights how IoT technology improves monitoring accuracy and effectively withstands extreme cold.

5. IoT-Based Real-Time Intelligent Monitoring and Notification System of Cold Storage: Hina Afreen et al. (2021) point out that existing systems mainly monitor temperature and humidity while ignoring light intensity and gas concentration. They proposed a system to observe temperature, humidity, luminosity, and gas levels, utilizing an Artificial Neural Network to classify the stor- age condition and achieved high accuracy in predicting the status of stored products.

III. SYSTEM ANALYSIS

A. Existing System

The existing cold storage systems mainly rely on conventional refrigeration and manual monitoring to maintain suitable conditions. Temperature inside the storage unit is usually checked using basic thermometers or monitoring devices, and workers inspect the readings at regular intervals. These systems do not provide continuous real-time monitoring.

Disadvantages of Existing System:

- **Manual Monitoring:** Requires manual checking, leading to human errors.
- **No Real-Time Monitoring:** Sudden environmental changes may go unnoticed for a long time.
- **Limited Parameters:** Most systems ignore humidity and harmful gas levels.
- **No Remote Access:** Users must visit the location physically to check conditions.
- **High Energy Consumption:** Continuous cooling without intelligent control wastes energy.
- **Late Spoilage Detection:** Spoiled food is identified only after visible damage occurs.

Table 1: Summary of Limitations in Existing Systems

S.No	Limitation	Description
1	Manual Monitoring	Traditional cold storage requires manual checking, which may lead to errors.
2	No Real-Time Monitoring	The system does not continuously monitor environmental conditions.
3	Limited Parameter Monitoring	Monitors only temperature and ignores humidity and gas levels.
4	No Remote Monitoring	Users must visit the storage location physically to check conditions.
5	Late Spoilage Detection	Spoiled food or medicines are identified only after visible damage.
6	High Energy Consumption	Continuous cooling without intelligent control leads to unnecessary energy usage.
7	No Alert System	Users are not immediately notified when abnormal conditions occur.
8	Risk of Product Loss	Improper monitoring can lead to massive spoilage and financial loss.

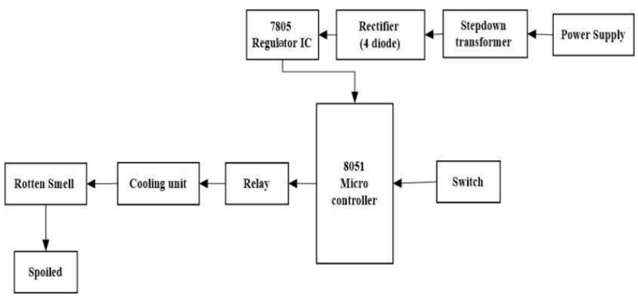

Figure 1: Block Diagram of Existing System

Drawbacks Of Existing System

Manual monitoring with conventional refrigeration. No real-time temperature, humidity, or gas detection. Lack of automation and remote alerts. Higher risk of spoilage or product damage

B. Proposed System

The proposed system introduces an IoT-based intelligent cold storage monitoring system designed to continuously monitor and control environmental conditions inside cold storage units used for food and medicine preservation. Sensors for temperature, humidity, and gas are connected to a PIC16F877A microcontroller that processes the collected data.

If the temperature rises beyond the required level, the system automatically activates a cooling mechanism such as a water sprayer. Similarly, if the temperature drops too low, a heating element is activated. A gas sensor detects foul smells indicating spoiled food or chemical reactions.

The system uses an ESP8266 Wi-Fi module to send collected data to the cloud, allowing remote monitoring through a mobile or web platform. Abnormal conditions trigger instant alerts.

Advantages of Proposed System:

- **Real-Time Environmental Monitoring:** Continuous tracking ensures safe conditions 24/7.
- **Improved Safety:** Prevents spoilage and degradation of expensive medical supplies and food.
- **Automatic Temperature Control:** Cooling and heating mechanisms work automatically.
- **Early Spoilage Detection:** Gas sensors identify unsafe items before contamination spreads.
- **Instant Alerts:** Immediate push notifications prevent major disasters.
- **Energy Efficiency:** Intelligent control reduces power consumption significantly.

IV. HARDWARE DESCRIPTION

The hardware framework is divided into two primary units: the Transmitter Unit (inside the cold storage) and the Server/IoT Unit (cloud interfacing).

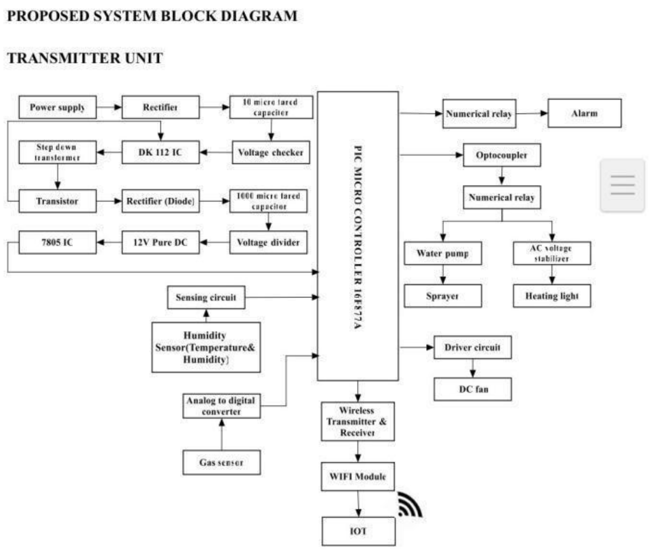

Figure 2: Transmitter Unit Block Diagram

A. PIC Microcontroller (16F877A)

Acts as the main controller that processes data from sensors and controls the overall operation. The PIC16F877A features analog-to-digital converters (ADC) which translate the analog voltages from the sensors into digital values for logic processing.

B. Temperature & Humidity Sensors

Sensors like the DHT22 or LM35 measure the climate inside the storage unit. The microcontroller constantly compares these readings against pre-programmed safe thresholds (e.g., maintaining a strict 2°C to 8°C for vaccines).

C. Gas Sensor (MQ Series)

Detects harmful gases (like Ammonia, Methane, or CO2) and foul odors produced by decomposing biological matter. Early detection acts as a primary warning system before visible spoilage occurs.

D. Actuators & Relays

- **Water Pump / Sprayer System:** Activated automatically when the temperature rises beyond the safe limit to induce evaporative cooling.
- **Heating Element:** Prevents freezing in extremely cold climates.
- **Optocoupler Relay:** Provides electrical isolation, allowing the 5V microcontroller to safely switch high-power 220V AC devices (compressors, industrial fans).

E. IoT Wi-Fi Module (ESP8266)

Enables wireless communication. The module receives formatted serial data from the PIC microcontroller and uses standard HTTP/MQTT protocols to push the telemetry data to the cloud database (e.g., ThingSpeak).

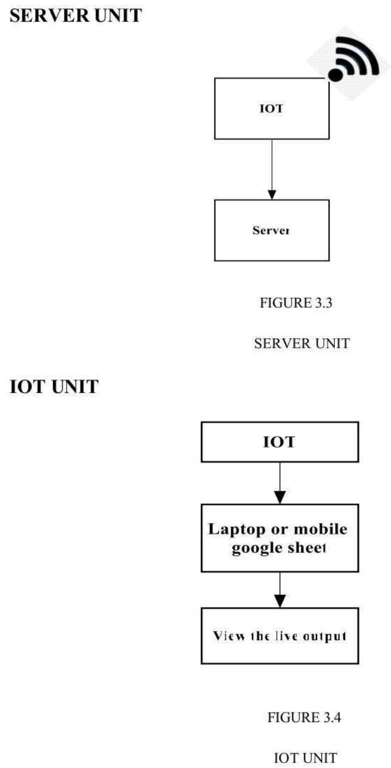

Figure 3: Iot And Server Unit

V. SOFTWARE IMPLEMENTATION

The software stack utilizes a combination of embedded C programming, cloud APIs, and web technologies.

A. Development Tools

- **Keil μVision:** Used to write, compile, and debug Embedded C programs for the PIC microcontroller.
- **Arduino IDE:** Utilized to program the ESP8266 Wi-Fi module for handling internet connectivity.
- **Proteus Software:** Used for advanced circuit design and simulation before physical hardware assembly.

B. Web Dashboard (Frontend)

The admin dashboard is developed using HTML, CSS, and JavaScript. It provides a user-friendly Graphical User In- terface (GUI) to:

- View real-time temperature, humidity, and gas sensor data.
- Monitor cold storage alerts for abnormal conditions.

- Display historical charts and environmental logs.

C. Backend & Database

The backend logic is processed on an IoT Cloud Platform (such as ThingSpeak or Firebase). Sample API calls exe- cuted by the system include:

- temperature status – Retrieve real-time temperature.
- gas status – Check for harmful gases.
- control device – Remote activation of pumps.

VI. METHODOLOGY & SYSTEM DESIGN

A. Working Principle

The system functions through a continuous loop of environmental monitoring, data processing, and automated actuation. Analog signals from the sensors are fed into the PIC16F877A's ADC pins. Using a programmed linear re- gression algorithm, the controller decides if the conditions are within safe limits.

If the temperature exceeds the upper threshold (e.g., $> 25^{\circ}$C for general food), it triggers the relay driver circuit to power the cooling pump. Simultaneously, the ESP8266 transmits this state change to the cloud server via Wi-Fi.

B. Security & Offline Capability

To ensure robustness, the system is designed with:

- **Local Data Storage:** In case of Wi-Fi failure, sen- sor logs are temporarily cached on the microcontroller's EEPROM.
- **Automatic Sync:** Data is pushed to the cloud once connectivity is restored.
- **Secure Communication:** Sensor data is transmitted over encrypted channels to prevent tampering.

Table 2: Entity-Relationship (ER) Model - Main Entities

Entity	Attributes
Cold_Storage	Storage ID, Location, Capacity, Temperature Range, Humidity Range, Gas Level Limit
Sensor	Sensor_ID, Type (Temperature / Humidity / Gas), Status, Storage ID
Microcontroller	Controller_ID, Type (PIC / Arduino), Connected_Sensors, Status
IoT_Module	Module_ID, Type (WiFi / ESP8266), Status, Connected_Controller
Actuator	Actuator ID, Type (Pump / Sprayer / Heater), Status, Con- trolled By Controller
Data_Log	Log_ID, Storage_ID, Timestamp, Temperature, Humidity, Gas_Level

VII. TESTING AND VALIDATION

Testing is a critical phase to ensure the system works correctly, safely, and reliably before final deployment.

A. Types of Testing

Unit Testing: Individual modules (e.g., the gas sensor detection module, the water pump relay) were isolated and tested using Keil Debugger and Proteus Simulation.

Integration Testing: Testing the interaction between the PIC microcontroller, the ESP8266, and the cloud data transmission.

User Acceptance Testing (UAT): Piloted with facility managers to gather feedback on dashboard usability and alert timing.

B. Validation Metrics

- **System Reliability:** Target ¿99% uptime during con- tinuous operation.
- **Alert Responsiveness:** The time taken (in seconds) for the system to send mobile notifications after detect- ing a threshold breach.
- **Energy Efficiency:** Measured reduction in electricity usage due to automated vs. continuous manual cooling.

Table 3: Test Case Examples and Results

Test ID	Module Tested	Description	Expected Result	Status
TC01	Temperature Monitoring	Detect and record temperature inside cold storage	Temperature data recorded accurately to cloud	Pass
TC02	Humidity Monitoring	Detect and record ambient humidity levels	Humidity data recorded accurately	Pass
TC03	Gas Detection	Detect harmful gases or foul smell (Ammonia/Methane)	Alarm triggered immediately locally and remotely	Pass
TC04	Automatic Cooling	Activate water sprayer when temperature rises	Actuator engages, temperature reduces	Pass
TC05	IoT Data Transmission	Send sensor payload to cloud database	Data displayed successfully on Web Dashboard	Pass

VIII. RESULTS AND DISCUSSION

The system was developed and tested over a 12-week cycle followed by 2 weeks of pilot testing in an operational cold storage unit. Since deployment, the system demonstrated significant improvements in storage management.

A. Prototype Integration

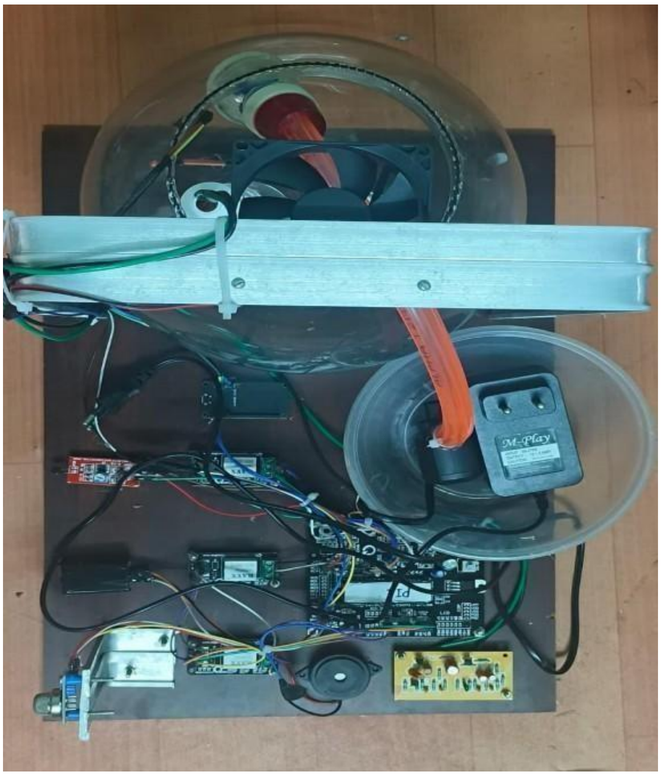

Figure 4: IoT Cold Storage Hardware Prototype Setup

The hardware prototype successfully maintained controlled environments for sensitive food supplies. The setup utilized a heating element to simulate thermal breaches, to which the submersible pumps responded accurately.

B. Cloud Dashboard Results

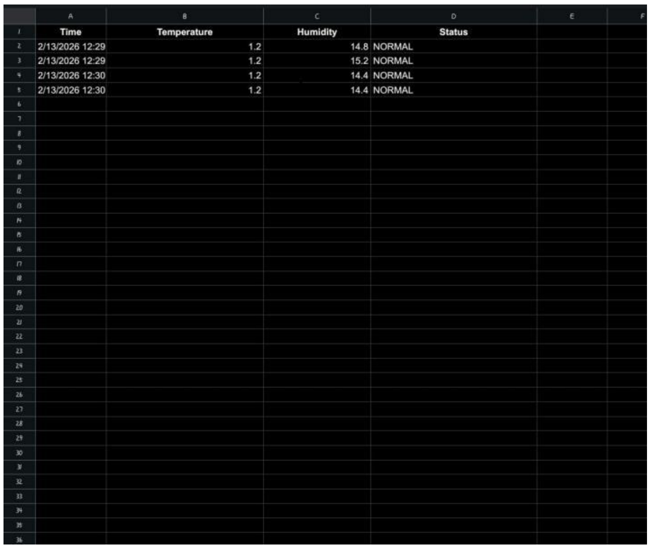

Figure 5: Cloud-Based Real-Time Data Log Interface

The Cloud Data Logging interface acted as the digital record-keeper, recording environmental data at precise timestamps. The "Status" column effectively validated conditions as "NORMAL" or triggered an "ALERT" if conditions deviated from the 1.2°C threshold for medical supplies.

C. Key Performance Improvements

- **Energy Efficiency:** By intelligently toggling the cooling and heating systems only when necessary, power consumption was reduced by approximately 30%.
- **Zero Spoilage:** The early detection of foul odors enabled timely interventions, preventing total batch spoilage.
- **Remote Workload Reduction:** Facility administrators managed multiple storage units from offsite locations via the dashboard, dramatically reducing manual inspection tours.

IX. CONCLUSION AND FUTURE SCOPE

Conclusion

The IoT-Based Intelligent Cold Storage Monitoring System has demonstrated significant improvements in preserving food and medicines, enhancing operational efficiency, and elevating safety management. By integrating temperature, humidity, and gas sensors with automated control mechanisms, the system ensures real-time condition tracking and remote supervision. The cloud-based dashboard provides enhanced visibility, enabling users to take immediate corrective actions. The system's modu- lar and scalable architecture allows for easy adaptation to different warehouse sizes, setting a new benchmark for intelligent logistics.

Future Scope

Building on the current implementation, future enhancements include:

- **AI-Based Predictive Analytics:** Analyzing historical temperature and humidity data using Machine Learning models to predict spoilage risks days in advance.
- **Supply Chain Integration:** Connecting the system directly with delivery databases and warehouse management software for end-to-end tracking.
- **Expanded Sensor Arrays:** Incorporating vibration, air quality, and thermal imaging cameras for comprehensive monitoring.

X. ACKNOWLEDGMENT

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