IoT-Based Cold Chain Monitoring System

Arun kumar J[1], Udaya Sindhu Gadadasu[2], Binay kumar Devavath[3], Abhinav kumar Thatha [4]
Dept. of ECE, Sreenidhi institute of science and technology Hyderabad, India

***Abstract*— Cold chain tracking has been of great significance to the quality and safety of temperature sensitive products like vaccines, medicine, dairy products, and foodstuffs. In most of the current systems, temperature controllers are monitored manually or not with real time notifications. This may cause damages to the product and loss of money in case temperature variations are not detected in time. Thus, the project is aimed at the creation of the IoT-based cold chain monitoring system with the help of sensors and a microcontroller. The system will be programmed to oversee the temperature, humidity, and door position constantly. It has two DS18B20 temperature sensors in order to enhance reliability by comparing the results and identifying potential faults. It will have a DHT22 sensor to sense humidity and a magnetic reed switch as a door sensor to sense when the door is open or closed. All the sensor data is collected and processed by the ESP32 microcontroller. The system monitors the temperature to ensure that it is at a safe temperature. When the temperature becomes too high or too low or when the door is left open, an alarm is sounded with the help of a buzzer to take instant measures. The system also allows offline data storage with the use of SD card which makes the data not lost when there is a network failure. After the internet is in place, the data stored is uploaded to the cloud so that it can be monitored remotely. This system offers a low cost, easy to use and dependable system of enhancing the safety of cold chains and preventing loss of products.**

Keywords— Internet of Things, Cold Chain Monitoring, Temperature sensor(DS18B20), Humidity sensor(DHT22), Door sensor(Magnetic Reed Switch), ESP32, Real time alerts.

I. INTRODUCTION

The cold chain systems are designed to store and deliver the temperature sensitive products like vaccines, medicines, dairy products and food items. Such products have to be kept at a certain temperature level to maintain their quality and efficiency. A slight fluctuation in the temperature can also cause changes in the safety of these products, particularly in the case of vaccines and medicines, whose effectiveness can be diminished due to improper storage.

Temperature monitoring in most of the current systems occurs either manually, or on simple recording instruments. These approaches lack efficiency in that they fail to avail continuous information or real-time information. Whether the temperature changes suddenly up or down, it might not become apparent so that the product is spoilt. In addition to it, humidity, the high number of door openings, and uneven cooling in storage units can impact product quality.

As the IoT technology has evolved, it is now possible to track the conditions both remotely and continuously. In the project, a cold chain monitoring system is created based on IoT and incorporating sensors and a microcontroller. The system will check the temperature and humidity in real-time and will check the values within the safe range. In the event that an abnormal condition is detected, it will give an alert so that prompt action can be undertaken. The system will be in such a manner that the information is stored offline and not over the internet. The information that has been stored is automatically copied to the cloud when internet connection becomes available.

It is a system that can be utilized in transportation and storage. It can be transported in refrigerated vehicles to observe the conditions during transportation. The primary objective of the project is to offer a straightforward, dependable and economical solution to better monitoring and lower the ease of damaged goods in cold chain systems.

II. LITERATURE REVIEW

Cold chain monitoring is a field of study that was significant because there are products that are sensitive to temperatures and therefore the need to preserve the quality and safety of these products. Various scholars have come up with various systems to enhance monitoring through the application of modern technologies[1].

Lee et al. research work was primarily concerned with the application of IoT technology to monitor the temperature in cold storage systems[2]. They used temperature sensors that were attached to a wireless communication system to transmit the data to a central server. This facilitated remote tracking and enhanced access of data. Nevertheless, their system relied primarily on the availability of constant internet connectivity and this restricts its functionality in those regions where network connections are weak.

Zhang et al. have introduced a real-time monitoring system based on the GSM technology[3]. Alerts were dispatched by SMS in this system whenever the temperature was higher than what was safe. This enhanced real time response, although the cellular network usage lead to increased power consumption. In addition, the performance of the system was reliant on the network availability to send messages.

In Kim et al. a cold chain monitoring system based on clouds was presented[4]. This system enabled people to view data remotely using cloud platforms, which enhanced accessibility and visualization of data. Nevertheless, the system was not dedicated to the offline data storage that could result in the loss of data in case of the network failure. It did not also have sensor fault detection mechanisms.

Patel et al. also suggested a system with several sensors in recent years to enhance accuracy and reliability[5]. The system was in a position to compare the readings of various sensors to eliminate measurement errors and enhance performance. This method revealed that multi-sensor systems are more trustworthy compared to single-sensor systems.

Equally, Sharma et al. designed an IoT-based monitoring system that had alert systems and data visualization capabilities[6]. Their system enhanced real-time monitoring and interaction with users. Nevertheless, it remained strongly reliant on network connectivity and did not have such functionality as door status monitoring or offline data storage.

Based on the studies above, it can be noted that there are significant advances in the existing systems as they have enhanced real-time monitoring and accessibility, however, they have shortcomings like dependence on network, offline storage and fault detection[7]. Therefore, this project aims to overcome these gaps by integrating real-time monitoring, offline data storage, multi-sensor reliability, and door status detection into a single system.

III. PROBLEM STATEMENT

Cold chain system applies in storage and transportation of temperature sensitive products including vaccines, medicines, dairy products and food items. The products should be kept in a certain range of temperature to guarantee their quality and safety. Nevertheless, it is a significant problem of the real world to keep these conditions in a continuous state.

In most traditional systems, temperature is measured manually or by simple data loggers. These are not real-time monitors and so, it is hard to notice any sudden change in temperature. Consequently, the damage of products might be done before anything can be done. There is also lack of capability to monitor the system remotely at other locations.

The other significant problem is the internet connectivity dependence. A large number of systems are entirely dependent on the internet to store and pass information. In the case of no network connection, data can be lost and it becomes hard to monitor. This generates a loophole in continuous tracking particularly in the transportation process or in remote locations.

Moreover, there are systems that have a single sensor and this can not provide the right reading in case of fault. Humidity and opening of doors are also not well checked which may influence the product quality.
Hence, the system is required to be able to offer real-time monitoring, remote access with cloud solutions such as ThingSpeak, data storage even when offline, and reliable sensing. The offered system can resolve these issues by employing the use of several sensors, data storage on the cloud, and offline to enhance reliability and minimize the chance of losing products.

IV. EXISTING SYSTEM AND SIMULATION

A. *Existing System*

The current situation is characterized by a predominance of manual solutions or simple temperature measurement tools as cold chain monitoring systems. Temperature is manually checked at set intervals in most of the storage facilities and transportation systems. These procedures are reliant on human eye and can result in fault or non-readings. Other systems incorporate data loggers to document temperatures, which fail to alert in real-time, thus making it hard to take instant action in case of abnormal conditions.

State of the art monitoring systems rely on cloud solutions and sensors. These systems can be remotely accessed and can visualize the data. Nevertheless, they are very reliant on uninterrupted accessibility to the internet. The data become vulnerable to loss in case there is a failure in the network and monitoring is also not reliable. A lot of current systems have a single temperature sensor and that might not be accurate in case there is a fault with the system.

Moreover, other significant factors like humidity and door status is not necessarily monitored. Temperature may fluctuate due to door opening, although this situation is usually not monitored by numerous systems. Moreover, data storage is not always provided online, so this leaves loopholes in continuous tracking when shipping products or in remote locations. On the whole, the systems that are currently in place are not very functional and do not have a combination of various monitoring features.

B. Limitations of the Existing System

Even though the current systems offer simplistic monitoring, they have a number of drawbacks:

i. Absence of Real-Time Notifications: Numerous systems fail to give real-time feedback whenever the temperature is too low or high.

ii. Internet dependency: Most systems are wholly dependent on internet connectivity, and thus any loss of data in case of a failure of the network.

iii. Single Sensor Application: A single temperature sensor can be used but will lead to wrong readings in case of sensor errors.

iv. No Offline Data Storage: The information is not able to be saved in the case of network problems, which influences constant monitoring.

v. No Door Monitoring: Door open/close status cannot be detected, and this may impact internal temperature conditions.

vi. Slow Response: The absence of immediate alert systems can cause a delay in response and product damage.

vii. Limited Integration: The current systems do not integrate all of the capabilities such as temperature, humidity, door status and data storage into a single system.

V. METHODOLOGY

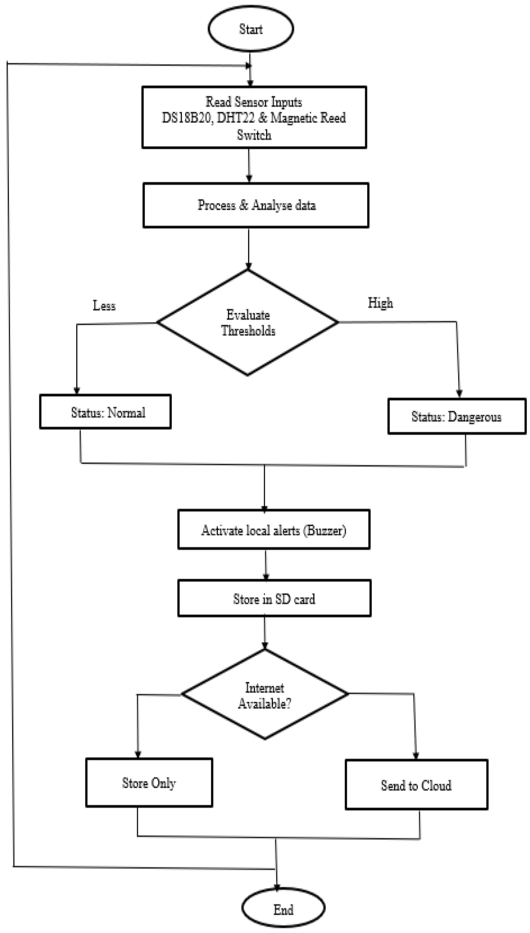


Fig 1: flowchart of Methodology

1) Sensor integration and data acquisition:

The proposed cold chain monitoring system is premised on a set of sensors which continuously monitor the environment in the storage container. With the assistance of the DS18B20 temperature sensor, the temperature is measured, and the humidity is verified with the help of the DHT22 sensor. In addition, it has a magnetic reed switch that will show whether or not the container door is open or was closed. These sensors are interconnected to ESP32 microcontroller as the CPU of the system. The information of all the sensors is retrieved periodically by ESP32. The temperature sensor provides digital temperature readings that are accurate and the humidity sensor provides the amount of moisture in the air. Reed switch gives a digital signal, indicating the door condition. All the data that has been measured is processed through the ESP32 which assesses the conditions based on whether they are within safe limits. The sensor values are compared to predefined threshold values which are used to continuously compare the sensor values to the system. When any of the parameters is beyond the safe range, then it is deemed to be an abnormal condition. The sensor data is also shown in 16x2 LCD screen in order to have real time information. This kind of mixed approach will ensure that a constant monitoring of different parameters and more reliability of the system will be ensured.

2) Local Data logging and Alerting:

The system also has an alert system, which notifies the users on the presence of dangerous conditions. In case the temperature or humidity are beyond the set limit, or the door has been left open and the ESP32 has been left on, then a buzzer is turned on to signal a danger state. This will provide a local notification and immediate response in time to prevent any spoiling of stocked goods. The system has an SD card module as a local data storage to increase the reliability of the data. Readings of the sensor are taken at periodic time (after every few seconds) and stored in a text file and time values are recorded. This will ensure no data is lost due to loss of internet connections. Logging process involves the writing of temperature, humidity and door status with time stamp. This will allow the users a chance to analyze the past data and identify abnormal trends. The local storage also implies that there would be no loss of data in the event of the network failure and thus the system is more certain than the ones that are solely relying on the cloud.

3) Data Transmission and Remote Monitoring:

Regarding remote monitoring the system can be used to send sensor data on the Thing Speak cloud platform using the built-in Wi-Fi system. The ESP32 writes the data obtained in the form of HTTP requests and sends them to the cloud at a certain frequency. Each of the parameters such as the temperature, humidity and the door status are designated a specific field in ThingSpeak channel. The cloud platform offers graphical representation of the data that enables the user to track the trends with time. This will help identify the temperature change and other issues with cold chain systems. The system postpones the uploading of data in about intervals of a few seconds, in accordance with the capacities of the cloud platform. The local storage and the cloud monitoring has also given the system the advantage of both data security and allowing the data to be accessed remotely. The internet enables users to check the system regardless of its location and the SD card enables a user to keep a copy of all the data recorded. This type of hybrid approach increases the level of reliability within the system and makes it applicable within real life system uses.

VI. PROPOSED SYSTEM

The proposed system proposes a system of an IoT-enabled intelligent cold chain monitoring system, which serves as the key node in ensuring safe environmental conditions within a storage container. In contrast to the traditional monitoring model, in which monitoring is based on periodical checks or cloud-based monitoring, the proposed model is centered on a real-time monitoring and local data storage and accessibility over a distance. The system is combined with various sensors and LCD display, a microcontroller and communication modules, the system monitors the environment parameters like temperature, humidity, and door status. The ESP32 microcontroller is the central control element, which gathers sensor data on a regular basis, processes it and engages in actions based on pre-set safety requirements. The LCD display will allow visualizing sensor data in real-time, and the communication module will allow transmitting the data to the cloud platform to monitor remotely.

A) System Architecture

The proposed system will comprise of one integrated unit which will comprise of sensing, processing, display, storage and communication types. The sensing unit has sensors that include a temperature sensor (DS18B20), humidity sensor (DHT22), and a magnetic reed switch to detect door status. These sensors gather real time information concerning environmental conditions within the container. The processing unit contains the ESP32 microcontroller, which interprets sensor data and reads it. The system has also an LCD display to monitor in real time, SD card module to store local data and a buzzer to generate alerts. Each element is harmonized as a means of constant control and effective functioning.

• *Temperature Monitoring*: The system constantly checks the temperature with the DS18B20 sensor. When the temperature is higher than the set safe limit it is an indication that there is a possibility of risk to the products stored. The ESP32 detects this situation and instantly triggers the alert system. The system use dual temperature sensors to ensure accurate monitoring and enable fault detection.

• *Humidity Monitoring*: The humidity level in the container is measured by DHT22 sensor. The quality of the stored products may be influenced by high humidity. When the humidity exceeds the threshold value, the system detects it as an abnormal situation and alerts.

• *Door Status Detection*: The opening and closing of the container door are sensed by a magnetic reed switch. When the door is left open over an extended period of time, it can cause temperature variation. The system is also used to check the door status continuously and send an alert as needed.

• *LCD Displ*ay: The system has a 16×2 LCD screen with the ESP32 via I2C. It shows the real time temperature, humidity and door status. This gives instant feedback to the user without being connected to any external devices.

• *Local Data Logging*: The sensor data are stored in SD card by the system at a regular time (after every 5 seconds). Stored information consists of temperature, humidity, and door status with the time. This makes sure that all information is stored even in the event of internet failure and enables past records to be analysed.

• *Cloud-Based Monitoring*: The ESP32 relies on its inbuilt Wi-Fi communication board to transmit real-time information to the ThingSpeak cloud solution. The data transmission is performed with the help of HTTP protocol with a certain frequency (about every 15 seconds). The cloud platform offers visualization of sensor data graphically, which allows users to remotely monitor conditions.

• *Alert Mechanism*: The system comes with a buzzer to alert the user whenever an abnormal condition is detected, like high temperature, high humidity, or a long time spent opening the door. This provides immediate notification and helps in taking corrective action.

• *Communication Module Role*: The Wi-Fi communication module allows the system to send the sensor data in real time to the cloud platform. It provides access remotely, constant monitoring and visualization of data in any location.

• *IoT Device Role*: The system works as an IoT device by gathering data through sensors, processing on the LCD, storing data on the LCD as a backup, and sending data to the cloud. This allows monitoring in real-time, automatic decisions and access remotely.

• *ESP32 Role*: The ESP32 is the central controller of the system. It processes sensor data, compares with a threshold, generates alerts, controls LCD displays, logs data to SD card and communicates with cloud. Its inbuilt Wi-Fi feature renders it to be suitable in IoT based application thereby guaranteeing effective and dependable system functioning.

• *Overall System Functioning*: The whole system works in a loop and is constantly reading sensor data, processing sensor data, monitoring abnormal conditions and sending alerts, displaying data on LCD, storing data locally at a rate of 5 seconds and sending data to the cloud at an approximate rate of 15 seconds. This combined system is reliable, as well as safeguarding the data and provides real-time tracking, which makes the system suitable in cold chain systems.

B) The Main Characteristics of the proposed system

The proposed cold chain monitoring system based on IoT is aimed at providing an efficient, reliable, and cost-effective solution to monitor temperature sensitive environment. The system aims at striking a balance between performance, energy efficiency, and affordability hence it is applicable in real life practice.

• *Low-Cost Implementation*: The system is constructed by using low-cost and readily accessible parts like ESP32 microcontroller, DS18B20 temperature sensor, DHT22 humidity sensor, and SD card module. This makes it cheaper than the conventional industrial monitoring system, which is applicable in small scale and low budget systems.

• *Low Power Consumption*: The ESP32 microcontroller has been created to operate on low power, hence consuming less power when executing continuous monitoring and communication functions. This allows the use of the system in battery-powered or portable systems where energy efficiency is a consideration.

• *High Processing Speed*: The ESP32 is fast enough to support real-time data acquisition, analysis and decision-making. It is rapid in processing sensor inputs and also reacts instantly to abnormal conditions resulting in fast system performance.

• *Optimized Memory Usage*: The ESP32 has sufficient memory to support various functions like sensor reading, data processing, and communication. Storage capacity can be further increased by the use of an SD card which will enable long term data logging without interfering with the performance of the system.

• *Fast Response Time*: The system constantly checks sensor data and identifies the abnormal states immediately. Alerts like the activation of buzzer will be activated as soon as threshold values are surpassed, which means that the critical situations are responded to as quickly as possible.

• *Efficient Data Handling*: The system adheres to the optimized data processing strategy: The sensor data is saved locally in SD card after every 5 seconds. The frequency of data transmission to the cloud is about 15 seconds. This will guarantee optimization of memory, bandwidth and power and also provide dependable data availability.

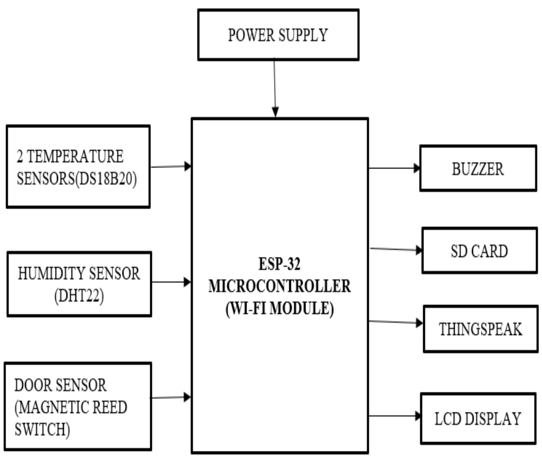
• *Local Data Backup*: Local storage of sensors data is done through the SD card module which offers high reliability. This will guarantee that none of the data will be lost once there is a problem with connecting to the internet and will enable the users to analyze the past data anytime.

• *Remote Monitoring Capability*: The system is based on Wi-Fi communication to transfer the data to ThingSpeak cloud platform. This enables the users to remotely monitor system parameters graphically, which enhances convenience and accessibility.

• *Scalable and Portable Design*: The system is small enough to be enclosed within a small insulated box. It is also scalable or expandable to include additional sensors or functionality as needed by the application.

• *Reliable and Continuous Operation*: The system works in a circle with continuous repetitive sensing, processing, alerting, storage and communication functions. This guarantees continuous monitoring and enhances the reliability of the system.

VII. BLOCK DIAGRAM



The block diagram is the general layout of the proposed cold chain monitoring system with IoT. It illustrates the interface between sensors, processing unit, storage, display and communication modules. The system will include temperature sensors (DS18B20), humidity sensor (DHT22), and magnetic reed switch to determine the status of the door. These sensors will continuously feed information to the ESP32 microcontroller which will receive the data and act as the central processing unit. The sensor data are processed by ESP32 and compared with a set of values representing a threshold. It takes the output elements, including the buzzer to generate alerts and the LCD display to show real-time measurements, based on the analysis. Data are also stored locally in SD card within the system as a backup. Also, the ESP32 sends the real-time recordings to ThingSpeak cloud through its inbuilt Wi-Fi module to monitor remotely. The power supply unit supplies the power required by all the components of the system to ensure that the system operates continuously.

VIII. OVERALL SYSTEM OPERATION

A. Hardware Implementation

The proposed cold chain monitoring system is built based on the IoT and combines sensing, processing, storage and alert to maintain constant monitoring of the environmental conditions. The ESP32 microcontroller is the heart of the system and serves as the central control unit and organizes all activities. It is connected to two temperature sensors (DS18B20) to give precise and reliable temperature readings at various locations within the container. By using two sensors, comparative analysis can be done and thus accuracy is enhanced and faults can be detected in the event of abnormal variance between the readings. Besides checking the temperature, a DHT22 sensor is employed to check humidity levels, making sure that moisture conditions do not exceed safe levels. A magnetic reed switch is built in to monitor the situation of the container door, which can be used to determine any unintended or extended opening that can have an impact on the situation inside. There is also an LCD display in the system which visualizes sensor values in real time enabling users to have a quick grasp of the current state without necessarily having to access external systems. In the case of alert generation, a buzzer is added to alert the users as soon as any parameter is beyond the pre-set values of threshold parameters. In order to guarantee reliability of the data, an SD card module is employed to store sensor readings locally at a fixed time interval. This will allow constant data recording even when there is no internet connection. The power supply is regulated to supply the whole system, and thus all the components are maintained at stable operation. The hardware design in general revolves around reliability, accuracy and real-time responsiveness.

B. Software Implementation

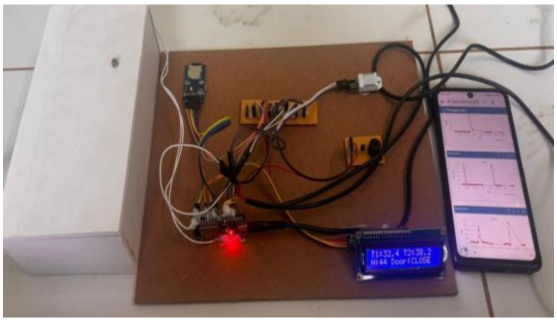
The system is implemented in the form of the software, created with the Arduino IDE, to program the ESP32 microcontroller. The software is designed in such a way that it is able to make continuous monitoring by a loop-based execution model. The temperature, humidity and door status sensor data are received in regular intervals and real-time processed. The data obtained is compared to the pre-set threshold values to identify whether the system is in a safe or critical condition. According to this analysis, the system executes various functions including the activation of the buzzer, changes the LCD display, and data are saved in the SD card. One of the critical features of the software design is its dual data processing system. To provide a backup of data and to ensure reliability, sensor data is written to the SD card in the shorter interval (once every 5 seconds). Meanwhile, the system sends real-time data to the ThingSpeak cloud platform at predetermined times (about every 15 seconds) via HTTP communication via Wi-Fi. The software will also guarantee effective utilization of memory and quick reaction to exceptional circumstances. It is set to undertake various activities including data acquisition, processing, storage, and communication promptly. Graphical visualization of the uploaded data is performed with the ThingSpeak platform, where it can be remotely monitored and analyzed. This integrated edge processing and cloud integration enables the system to be efficient, reliable, and applicable in the real-time cold chain application.

Algorithm: Cold Chain Monitoring & Alert System
BEGIN
1.Power ON the system.
2.Initialize ESP32 microcontroller.
3.Connect ESP32 to wi-fi network.
4.Develop ThingSpeak account and channel.
5.Reserve Write API Key and set up as code.
6.Initialize sensors:
  DS18B20 (Temperature sensors)
  DHT22 (Humidity sensor)
  Reed switch (Door sensor)
7.Initialize output devices:
  LCD display
  Buzzer
8. Initialize SD card MODULE
9.Show LCD System Ready.
10.Begin running monitoring loop.
11.Read temperature values (Sensor 1 & Sensor 2).
12.Read humidity value.
13.Read door status.
14.Compare the two values of temperature sensors.
15.In case of high mismatch:
  Identify possible sensor fault.
16.Compare temperature with threshold.
17.Compare humidity with threshold.
18.Check door status (open/closed).
19.Providing that all parameters are within safe limits:
Condition = SAFE
20.Else
Condition = DANGEROUS
21.In case of SAFE condition:
  Turn OFF buzzer
22.In case condition is DANGEROUS:
  Activate buzzer
23.Record data in SD card (intervall of 5 s).
24.Check Wi-Fi connection.
25.If connected:
Send data to ThingSpeak (~15 seconds)
26.Else
Only carry on with local storage.
27.Repeat process continuously.
END

IX. RESULTS AND DISCUSSION

Output 1: Normal State

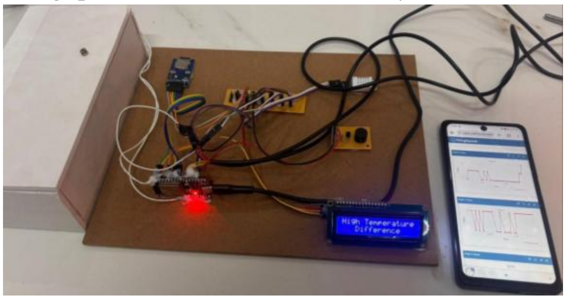
Explanation: The figure demonstrates the IoT-based cold chain monitoring system in the safe mode. The LCD shows the real-time values of temperature, humidity and door condition in fixed limits. The buzzer is OFF, which means that there is no risk as everything is normal. The sensor data are constantly monitored and processed by the ESP32. At the same time, information is sent to ThingSpeak cloud and shown on the mobile to be monitored remotely.



Output 2: Dangerous State

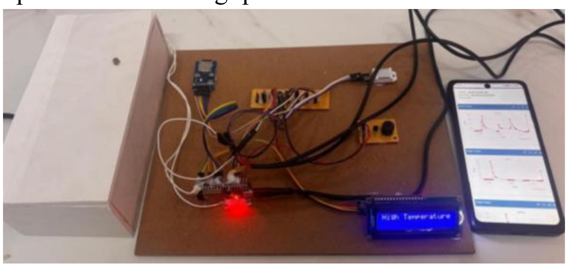
Case 1: High Temperature Difference

Explanation: The figure indicates that the system has detected that there is high difference in temperature between sensors indicating abnormal condition. The LCD shows a High Temperature Difference, which proves that there is something wrong, confirming the fault of a sensor or that it is not a safe environment. This is categorized under dangerous condition in the system. Consequently, the buzzer is set to constantly alert the user. The information is also relayed to ThingSpeak cloud to monitor remotely.



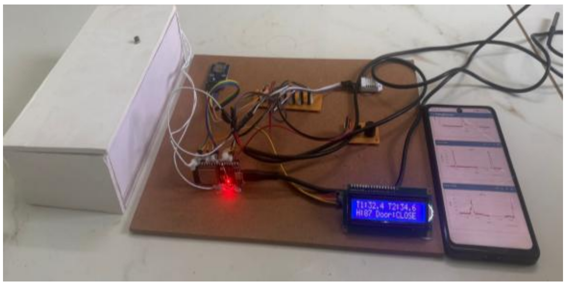
Case 2: High Temperature

Explanation: The system will notice that the temperature is higher than the safe limit as set. The LCD shows the High Temperature which is not a safe storage condition. This is categorized as a hazardous condition, that can rot away stored products. The buzzer is activated in order to give an immediate alarm. At the same time, the data is updated on the ThingSpeak cloud.



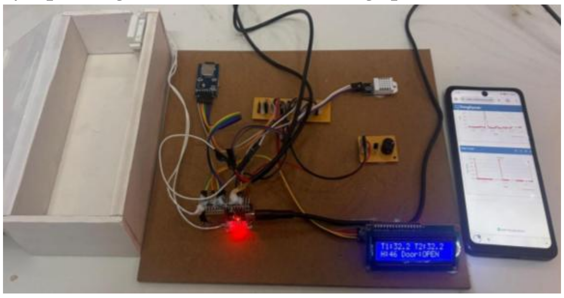
Case 3: High Humidity

Explanation: The figure indicates a situation when the humidity is above the safe level. The LCD shows the abnormal humidity values, which means that it is not a safe environment. This is a dangerous condition as defined by the system. Buzzer is used to indicate the user that he or she should take action immediately. The humidity data is also sent to the cloud to be monitored.

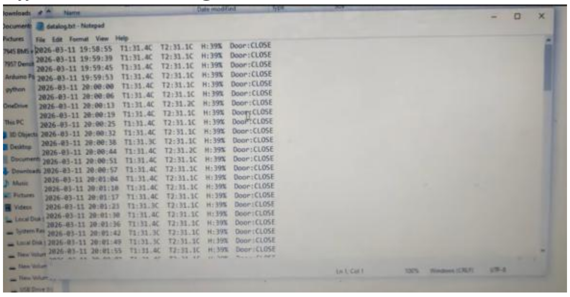


Case 4: Prolonged Door Open Condition

Explanation: The system identifies that the container door is open, which is indicated on the LCD display. When the door is open long enough, the door can cause a variation in temperature and spoil the products. Therefore, it is a dangerous condition. The user is immediately notified through the buzzing which is turned ON. Remote monitoring is also done by updating the status on the ThingSpeak cloud.



Offline Data Storage:



datalog.txt - Notepad

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2026-03-11 19:58:55 T1:31.4C T2:31.1C H:39% Door:CLOSE
2026-03-11 19:59:39 T1:31.4C T2:31.1C H:39% Door:CLOSE
2026-03-11 19:59:45 T1:31.4C T2:31.1C H:39% Door:CLOSE
2026-03-11 19:59:53 T1:31.4C T2:31.1C H:39% Door:CLOSE
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2026-03-11 20:01:10 T1:31.4C T2:31.1C H:39% Door:CLOSE
2026-03-11 20:01:17 T1:31.4C T2:31.1C H:39% Door:CLOSE
2026-03-11 20:01:23 T1:31.3C T2:31.1C H:39% Door:CLOSE
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2026-03-11 20:01:42 T1:31.3C T2:31.1C H:39% Door:CLOSE
2026-03-11 20:01:49 T1:31.3C T2:31.1C H:39% Door:CLOSE
2026-03-11 20:01:55 T1:31.4C T2:31.1C H:39% Door:CLOSE

X. CONCLUSION

The cold chain monitoring system proposed as an IoT-based solution will offer an efficient and effective solution to ensure the safe environmental conditions of temperature-sensitive products. Through sensors, the system tracks the temperature, humidity and door status and processes the data with an ESP32 microcontroller. It guarantees that any abnormal conditions are immediately identified and alerts are provided to avoid possible harm.

Local storage of data with the help of an SD card and cloud-based monitoring via ThingSpeak enhances the reliability and accessibility of data. Dual temperature sensors help to improve accuracy and basic fault detection, improving system reliability. The system is low cost, energy efficient and simple to implement and thus can be adopted into practical use.

On the whole, the project helps to illustrate how the IoT technology can be implemented to enhance the cold chain monitoring process by offering real-time tracking, data backup, and remote monitoring, minimizing product loss, and maintaining quality.
The system proposed can also be advanced by incorporating mobile applications that will give real time notifications and alerts to the users. Enhanced communications protocols like MQTT may be employed to enhance the efficiency and reduce latency of data transmission. GPS modules can also be added to the system to provide location tracking in transportation based cold chain system. Other capabilities, including automatic cooling, machine learning-based forecasting of temperature changes, and battery optimization measures can also enhance the work of systems. It can be integrated with state-of-the-art cloud solutions and dashboards to offer superior analytics and decision-support. Such advances can turn the system into something more scalable, intelligent and can be applied in large-scale industrial applications.

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