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ColdTrace: A Low-Cost Cold Storage Performance Tracker with Smartphone Temperature Alerts

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Abstract: *Temperature control is the most important requirement in cold storage, since perishable goods such as fruits, vegetables, dairy, meat and fish spoil quickly outside their safe range. Periodic manual thermometer checks cannot catch a temperature rise that begins and grows between two inspections. This paper presents ColdTrace, a low-cost embedded Internet of Things (IoT) node that monitors the temperature inside a storage unit and warns the user when a set limit is exceeded. An ESP32-WROOM-32 microcontroller reads a DS18B20 digital sensor over a single-wire interface and compares each reading with a threshold in software. When the threshold is crossed, the board uses its built-in Wi-Fi to send a "PROBLEM ALERT" to the user's smartphone through the Blynk server. Because the sensor gives a digital output, no analog-to-digital conversion circuit is needed, which keeps the hardware simple. The design, working principle, circuit connection and alert logic are described. ColdTrace reduces dependence on manual inspection and offers an affordable, easily reproducible monitoring option for small cold storage units*

Keywords: Cold storage monitoring, ESP32, DS18B20, Blynk, threshold detection, Internet of Things

I. INTRODUCTION

Cold storage underpins the food, agricultural and pharmaceutical supply chains. Perishable goods such as fruits, vegetables, dairy, meat and fish lose quality fast once they leave their recommended temperature band, and one failed unit can mean a serious financial loss. Good cold storage therefore needs more than a working refrigeration plant; it also needs constant confirmation that the intended temperature is really being held.

In many small and medium facilities, an operator still walks up to a thermometer at set times and notes the value. This approach relies on staff being present and attentive. A door left ajar, a compressor breakdown or a power cut can go undetected until the next round. Low-cost embedded devices that sense temperature and report it wirelessly are now practical thanks to progress in embedded systems and the Internet of Things (IoT), and several cold storage monitoring systems have been reported [1], [2], [3].

This paper introduces ColdTrace, a Cold Storage Performance Tracker based on the ESP32-WROOM-32 microcontroller. A DS18B20 digital sensor measures the temperature and sends it to the microcontroller on a single wire. The program compares each reading with a preset limit. When the limit is passed, the built-in Wireless Fidelity (Wi-Fi) radio sends the message "PROBLEM ALERT" to the user's phone through the Blynk server, giving the user a chance to act before the stored goods are damaged.

The work makes three contributions: (i) a compact monitoring node built from just a microcontroller, a digital sensor and a pull-up resistor; (ii) a software-based threshold check in which both the limit and the sampling interval can be edited without touching the hardware; and (iii) phone alerts routed through Blynk, which removes the need for any

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extra communication module. Section 2 surveys related work, Section 3 presents the proposed system, Section 4 covers implementation, Section 5 discusses results and limitations, and Section 6 gives the conclusion and future scope.

II. LITERATURE REVIEW

IoT-based monitoring of cold storage and cold chains has drawn growing interest. Husainy et al. [4] reviewed IoT-based automation and monitoring systems for cold storage, while Mitkari [5] surveyed the IoT techniques applied to the same task. Together they outline the sensing and communication building blocks commonly used.

A number of studies pair live monitoring with notifications. Afreen and Bajwa [1] built an intelligent real-time monitoring and notification system for cold storage, and Awasthi et al. [6] described an IoT-based cold chain method that issues real-time alerts for perishable goods. Yadav et al. [7] created a remote monitoring solution for a cold storage warehouse. Nanwatkar et al. [2] went a step further with a food cold storage system that monitors and also controls storage conditions, and Appasani et al. [8] examined analytical modelling and optimal control of a cold store deployed with large-scale IoT.

The studies nearest to ours are low-cost, open-source and small in scale. Tang et al. [9] used an Arduino to monitor temperature and humidity in a small fruit and vegetable cold store, and Ramírez-Faz et al. [10] tracked the temperature of retail refrigerated cabinets using open-source hardware and software. Marathe et al. [11] used an ESP32-S3-WROOM-1 module with the Message Queuing Telemetry Transport (MQTT) protocol for data monitoring and visualisation, showing that ESP32-family modules make a suitable base for networked monitoring nodes. Mandal et al. [12] described a solar-powered system measuring temperature and relative humidity in cold stores, and Baghel et al. [13] proposed an integrated sensing and logging solution that retains a record of measured conditions.

Other work targets wider or larger environments. Cil et al. [14] examined real-time cold chain monitoring at a container port, Han [15] developed a cold chain logistics system on fifth-generation (5G) ubiquitous IoT, and Wu et al. [16] tested a real-time cold chain logistics monitoring system experimentally. Feng et al. [17] paired IoT monitoring with electronic-nose detection of spoilage in salmon, Sarmah and Aruna [18] sensed food quality and quantity in cold storage, and Umamaheswari et al. [3] used IoT for stock management. Data trustworthiness and security have been addressed too: Doubiz et al. [19] anchored IoT cold chain data to a blockchain for auditability, and Prasad et al. [20] proposed an artificial intelligence and machine learning (AI/ML) based intrusion detection framework for IoT-enabled cold storage monitoring.

A common thread in this literature is reliance on custom cloud platforms, several sensors, gateways or logistics-scale infrastructure, all of which add cost and complexity that small storage units can ill afford. What such units need is a focused design that makes the temperature decision on the microcontroller itself and sends the warning straight to the owner's phone through an existing notification service. ColdTrace targets this gap with the ESP32-WROOM-32, the DS18B20 sensor, a software threshold check and a Blynk phone alert.

III. PROPOSED SYSTEM

3.1 System Overview

ColdTrace has three parts: a sensing unit, a processing and communication unit, and a notification path. The DS18B20 measures the temperature of the storage space and passes the value in digital form to the ESP32 along one data line. At regular intervals the ESP32 reads this value and compares it with a limit set in the program. While the temperature is acceptable, the system simply keeps watching. Once the limit is crossed, the ESP32 sends "PROBLEM ALERT" over Wi-Fi to the Blynk server, which forwards it to the user's phone. Fig. 1 shows the block diagram and Table 1 lists the components.

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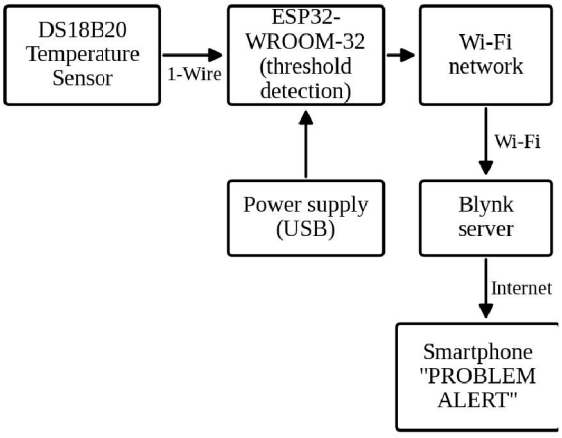


Fig -1: Block diagram of the proposed ColdTrace system

Table -1: Components of the ColdTrace system

Component	Function
ESP32-WROOM-32	Main controller and Wi-Fi communication
DS18B20	Digital temperature sensing
4.7 kΩ pull-up resistor	Pull-up of the 1-Wire data line
Jumper wires	Circuit connections
USB data cable	Power supply and programming
Wi-Fi network	Wireless link to the internet
Blynk server and application	Alert relay and smartphone notification
Smartphone	Receives the “PROBLEM ALERT” notification
Laptop with Arduino IDE	Programming and testing

3.2 Hardware Description

The ESP32-WROOM-32 is a Wi-Fi and Bluetooth module built around Espressif’s ESP32 system on chip. Its dual-core 32-bit processor runs at up to 240 MHz, and it includes 520 KB of static random access memory (SRAM) along with integrated flash for the program. It supports Wi-Fi (IEEE 802.11 b/g/n, 2.4 GHz) and exposes several general purpose input/output (GPIO) pins working at 3.3 V logic. As the wireless radio is part of the module, no outside communication hardware is needed.

The DS18B20 is a digital temperature sensor that talks over a 1-Wire interface, needing a single data line (DQ) besides power and ground. The conversion to a digital number happens inside the sensor, so the microcontroller obtains the value directly with no external analog-to-digital converter. Table 2 lists its main specifications. Its range of −55 °C to +125 °C comfortably includes the sub-zero temperatures of cold storage, and because every device carries a unique 64-bit serial code, extra sensors can later be attached to the same data line to cover more measurement points. A waterproof probe version also exists, which suits damp cold-room conditions.

Table -2: Key specifications of the DS18B20

Parameter	Specification
Interface	1-Wire (single data line)
Temperature range	−55 °C to +125 °C

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Accuracy	±0.5 °C from −10 °C to +85 °C
Resolution	9 to 12 bits (programmable)
Supply voltage	3.0 V to 5.5 V
Identification	Unique 64-bit serial code

The 1-Wire line is open-drain, so it has to be held at the supply voltage (VDD) by a resistor of roughly 4.7 kΩ placed between DQ and VDD. This inexpensive part is essential for dependable communication between the ESP32 and the sensor. A universal serial bus (USB) data cable both powers the board and lets a laptop program it, and jumper wires allow the connections to be made without soldering. The installation site needs a 2.4 GHz Wi-Fi access point with internet access, and the user's phone must run the Blynk application to receive the alert.

3.3 Software Requirements

The firmware is written in the Arduino integrated development environment (IDE) with ESP32 board support. The OneWire and Dallas Temperature libraries manage the 1-Wire bus and the DS18B20, the WiFi library handles the network connection, and the Blynk library links the ESP32 to the Blynk server. During testing, the IDE's serial monitor is used to check the readings and to set the threshold.

3.4 Working Principle

Once powered through USB, the ESP32 sets up the DS18B20 interface and joins the available Wi-Fi network. In each sampling cycle it triggers a temperature conversion, reads the result and compares it with the limit held in the program. If the temperature is within the limit, the controller idles until the next sampling interval. If the limit is exceeded, the event is classed as abnormal and the ESP32 sends "PROBLEM ALERT" over Wi-Fi to the Blynk server, which passes it on to the phone. The cycle then restarts and repeats without end, so the unit stays under watch without human involvement. Fig. 2 summarises the process.

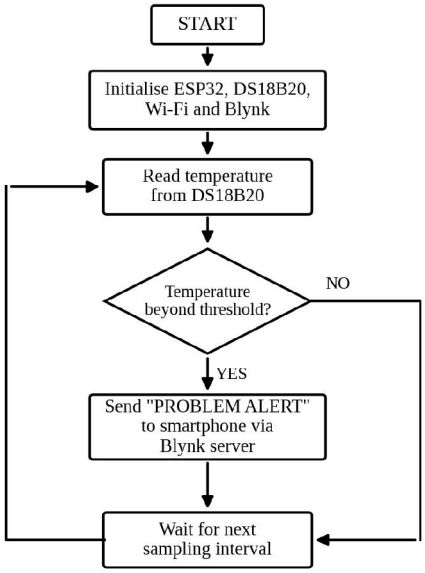


Fig -2: Flowchart of ColdTrace operation

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IV. IMPLEMENTATION

4.1 Circuit Connection

Fig. 3 shows the wiring. The ground (GND) pin of the DS18B20 goes to the GND of the ESP32 board, and the sensor's VDD pin goes to the board's 3.3 V supply. The DQ pin connects to a GPIO pin that is named in the program, and the pull-up resistor sits between DQ and VDD. Power comes in through the board's USB connector.

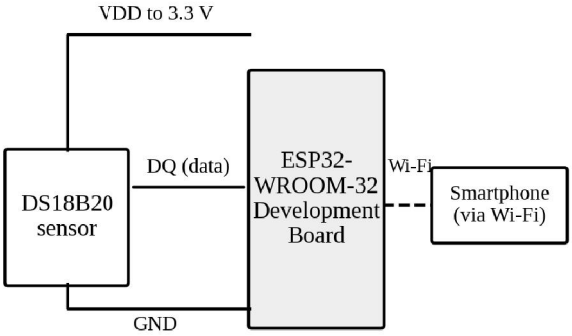


Fig -3: Circuit connection of the DS18B20 sensor with the ESP32 board

4.2 Threshold Detection and Alert Logic

The threshold check runs wholly in software, so no comparator circuit is required. The temperature limit and the sampling interval are declared as constants in the program. A limit of 8 °C with a 5 s interval could be used for chilled goods, for instance, and both can be altered to suit other products with no hardware change. In every cycle the ESP32 requests a conversion, reads the value through the DallasTemperature library and tests whether it is above the limit. If so, the alert routine sends "PROBLEM ALERT" to the phone; if not, the program waits for the next interval. In the current logic the alert routine is called in every sampling cycle in which the condition remains true.

4.3 Blynk Notification

The Blynk server sits between the ESP32 and the phone. The ESP32 reaches it through the Wi-Fi network, and when the alert routine runs, the message is passed to the Blynk application on the phone, which displays it as a notification. The service thus needs the ESP32 to have a working Wi-Fi connection with internet access and the phone to be online, which lets the user be informed even when far from the storage site.

V. RESULTS AND DISCUSSION

5.1 Operation of the System

In operation, the ESP32 reads the DS18B20 once per sampling interval and prints the temperature on the serial monitor. While the value stays within the limit, nothing further happens. When it goes above the limit, the program prints "PROBLEM ALERT" and forwards the alert to the user's phone through the Blynk server. Because measurement is automatic at each interval, it takes the place of periodic manual checks, and a temperature rise caused by an open door, a compressor failure or a power interruption can be reported at the next sample instead of the next inspection.

5.2 Comparison with Manual Monitoring

Table 3 sets ColdTrace against conventional manual monitoring on the aspects that matter most to small cold stores.

Table -3: ColdTrace compared with manual monitoring

Aspect	Manual monitoring	ColdTrace
Measurement	Periodic thermometer reading	Automatic, every sampling interval

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Operator	Must be present	Not required
Fault between inspections	May go unnoticed	Detected at the next sample
Alert to remote user	None	Smartphone alert through Blynk
Records	Manual register, prone to errors	Readings on the serial monitor
Hardware	Thermometer	ESP32, DS18B20 and pull-up resistor

5.3 Advantages and Limitations

ColdTrace offers timely notification, low cost and simplicity. The alert reaches the phone as soon as the limit is exceeded, the Wi-Fi radio is already built into the ESP32, and the DS18B20's digital output avoids any analog signal conditioning. Since the threshold check lives in software, the limit and sampling interval can be tailored to different products without altering the hardware.

There are also limitations. The system needs a Wi-Fi network with internet access at the site because alerts pass through the Blynk server. Changing the threshold means editing the program, only one measurement point is used, and the USB-powered node has no battery backup, so a power failure halts the monitoring itself. The DS18B20's ±0.5 °C accuracy is specified from −10 °C to +85 °C, which spans the normal range of chilled storage. Quantitative figures such as measurement error and alert delay were not measured in this work and are left for future evaluation.

VI. CONCLUSIONS AND FUTURE SCOPE

We have designed ColdTrace, a low-cost cold storage performance tracker built from an ESP32-WROOM-32 microcontroller and a DS18B20 digital temperature sensor. The ESP32 reads the temperature, tests it against a preset limit in software and, when the limit is exceeded, sends "PROBLEM ALERT" to the user's phone through the Blynk server. The design is simple, modular and easy to reproduce, as it relies on widely available parts and open development tools, and it reduces reliance on manual thermometer checks.

Several improvements are possible. Logging temperature data and displaying it on a cloud platform or mobile dashboard would let users review the history, as in [13] and [11]. A humidity sensor and battery or solar power could be added, as in [12], and further DS18B20 sensors could share the same data line to cover more measurement points. Extra alert channels such as short message service (SMS) or e-mail, a local buzzer, and a limit on repeated alerts would make notification more dependable. The monitoring function could also be extended to control the refrigeration unit [2], and product-quality sensing [17], [18], secure communication [20] and tamper-evident records [19] could be explored for more demanding uses.

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