

Smart Medicine Transportation Box for Injectable Medications

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Abstract - The stability of temperature sensitive drugs like insulin, biologics, and certain antibiotics depends upon stringent cold chain processes and require storage between 2 °C and 8 °C. Traditional means of transportation which use passive ice packs do not have active temperature controls. On the other hand, portable refrigerators are heavy-duty and need constant power supply. This research explores PHARMASECURE; an Internet of Things (IoT) based smart transport box with active temperature regulation and biometric security measures with real-time tracking capabilities. The system utilizes ESP32 microcontroller coupled with DHT11 temperature and humidity sensors to continuously monitor the environment. A closed loop control mechanism switches on the Peltier thermoelectric cooling module via relay in case temperatures are outside safety limits. Biometric security is provided through fingerprint scanner R307 which uses the data provided by it to enable/disable SG90 servo motor actuated lock. Real-time location of the box is determined with the help of Neo-6M GPS module and data from all sensors is sent to the Arduino IoT Cloud dashboard. The results indicate that cooling occurs within 180 seconds, the temperature control is precise by ± 1 °C and biometric recognition accuracy is 97%, whereas cloud synchronisation delay is 1.5 seconds.

Key Words: Pharmaceutical Cold Chain, ESP32, Peltier Cooling, Fingerprint Authentication, IoT Cloud, Healthcare Logistics.

1. INTRODUCTION

Maintaining temperature-controlled medicines at their required temperature and condition is a big challenge in healthcare logistics today. Medicines like insulin and self-injected antibiotics need to be kept cool at temperatures

between 2 °C and 8 °C to keep their protein structures intact. If the temperature changes, it can cause changes in the chemical structure of proteins, which means the medicine will not work and patients will suffer from risks. Insulins are mainly used to regulate and maintain blood glucose (sugar) levels. It is essential for the treatment and management of Type 1 diabetes and are widely prescribed for the management of advanced Type 2 diabetes. Injectable Antibiotics are mainly utilized for the treatment of severe bacterial infections and are administered when oral medications are ineffective or insufficient to fight the infection.

There are ways for transporting temperature-controlled medicines but the growth of home-based healthcare and vaccination campaigns in developing countries has shown that these methods are not good enough. Most of the time medicines are transported using cooling methods like insulated pouches and gel packs. This method does not have any cooling so the medicines are affected by the temperature outside. Another option is to use refrigerators but they are heavy and need to be connected to a power source all the time. The biggest problem is that there is no way to ensure the medicines are safe or to control the transportation process from a distance.

New technologies like embedded computing and IoT can help solve these problems. By combining temperature control, monitoring and wireless connectivity into one device we can create a smart storage solution for medical items. This study proposes a driven solution that makes the following contributions:

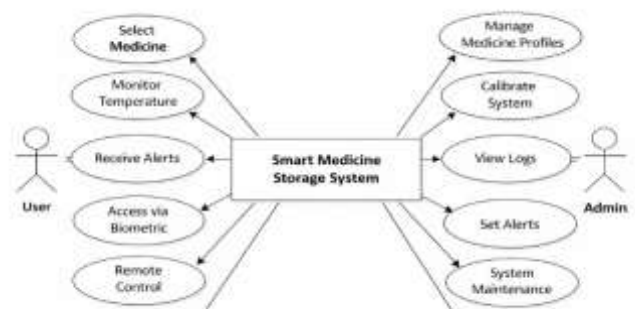
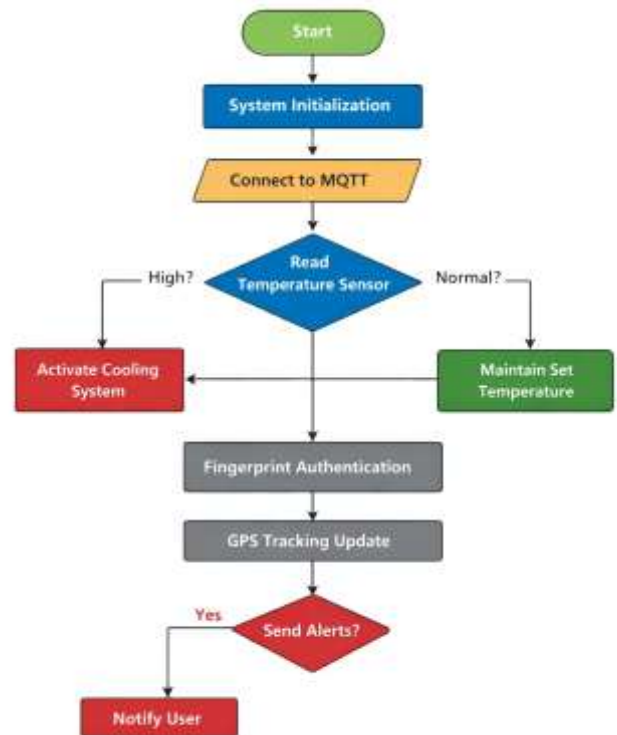
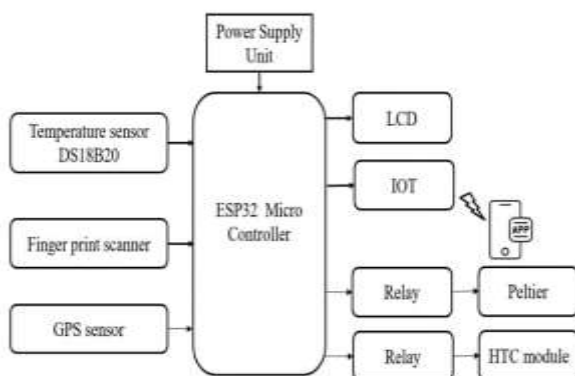
* The hardware design that combines an ESP32 controller, DHT11 sensors and Peltier thermoelectric modules to regulate the temperature of temperature-controlled medicines.

* The use of the R307 reader and an SG90 servo motor to ensure access security with full digital accountability for temperature-controlled medicines.

* The provision of real-time tracking services via Neo-6M GPS and Arduino IoT Cloud data synchronisation for temperature-controlled medicines.

* Experimental testing that proves temperature reduction, biometric recognition efficiency and reliable remote monitoring of temperature-controlled medicines at the level of field operations, in pharmaceutical logistics.

Our solution that uses new technologies to keep temperature-controlled medicines safe and effective. By using this method, we can ensure that temperature-controlled medicines are transported and stored at the required condition, which means patients will receive effective treatment and will not suffer from long-lasting diseases. The use of this can also help reduce the risks associated with temperature-controlled medicines and improve the quality of healthcare logistics.



2.RELATED WORK

There have been many recent advancements in making healthcare logistics systems digital, although most have concentrated exclusively on passive monitoring. Abdulkadhim et al. proposed an MQTT-based pharmacy monitoring system with the help of RFID and Raspberry Pi to monitor medicines and decrease human error. This system works well in terms of inventory management, but it does not provide active temperature monitoring or security features for transportation.

In terms of cold chain logistics, Le et al. developed a smart specimen transport system that uses RFID and NB-IoT for hospital laboratories to ensure constant monitoring of temperature and detecting anomalies. However, such a solution highly depends on NB-IoT, which is rarely available in rural areas. Bhatti et al. improved the security of medicine transportation by combining sensors with MQTT and secure SMS services

to guarantee alerts in areas where the internet may not be readily accessible.

As stated by Islam et al. a detailed review of IoT capabilities and protocols for medical care has been done which concludes that the protocol is indeed ideal for transmitting information on patients with minimal delays. The major gap pointed out by Islam et al. is that most existing systems only do either patient monitoring or location tracking without including autonomous cooling and biometric security features. In order to fill this research gap, our solution includes all three aspects into a single portable device.

3.METHODOLOGY

3.1 System Architecture

The proposed system will be built as an intelligent and portable temperature-controlled module that runs under control of the ESP32 microcontroller. The system will run in an uninterrupted loop of a closed loop process. DHT11 sensor senses the internal temperatures and humidity. It sends digital signals every second to the ESP32. If the controller identifies that temperature exceeds the upper limit value (8 °C), then it energizes a 5V relay module, which in turn powers the TEC1-12706 Peltier thermoelectric cooling module and a cooling fan. When the temperature drops to its safe lower value (2 °C), the relay module gets de-energized.

For authentication purposes, the R307 fingerprint scanner is connected to ESP32 microcontroller using UART. Successful matching with stored templates results in generation of PWM signal from ESP32 to power up an SG90 servo motor to physically unlock the electronic lock. A Neo-6M GPS module continuously tracks and obtains coordinates of device. The ESP32 combines the sensor values, GPS coordinates and logging information and transmits the data to the IoT cloud server over a Wi-Fi connection. Local data is displayed using 16x2 LCD screen.

3.2 Control Algorithm

The system's intelligence relies on its control algorithm. When it powers up, the ESP32 gets all sensor peripherals ready and connects to Wi-Fi. In the main loop, the controller checks the DHT11 sensor. If the temperature goes over 8 °C, the digital pin linked to the relay is set HIGH, activating the Peltier module. If the

temperature falls below 2 °C or safely returns to the 2–8 °C range, the pin goes LOW.

At the same time, the system polls the fingerprint scanner. If an authorized fingerprint ID is recognized with a confidence score above 50, the servo rotates to 90 degrees to unlock the box, and an "Authorized Access" log gets sent to the cloud. If an unauthorized fingerprint shows up or if the scanner times out, the servo stays at 0 degrees (locked), and an "Unauthorized Alert" is sent to the IoT dashboard. This ensures ongoing environmental adjustment and tight access control without needing human help.

3.3 Temperature Regulation Mechanism

The temperature control system uses a closed-loop feedback system to keep the temperature between 2 °C and 8 °C, which is the safe range for storing medicine. The DHT11 sensor keeps an eye on the inside of the device all the time and sends real-time data to the ESP32. The controller uses this information to turn on the TEC1-12706 Peltier module through a relay when the temperature goes above the limit. A cooling fan is used with the Peltier module to help it get rid of heat more quickly and work better. This automated regulation makes sure that the temperature stays stable while using less power and preventing temperature changes.

3.4 Biometric Security Implementation

To make sure that only authorized people can get into the medicine storage unit, the system uses a fingerprint-based authentication system. The R307 fingerprint module saves templates for authorized users and talks to the ESP32 using the UART protocol. The module scans and compares input fingerprints with stored data while it is in use to confirm identity. When the ESP32 successfully verifies the user's identity, it sends a PWM signal to the SG90 servo motor to unlock the compartment. Attempts to access the system without permission are logged and detected, which makes access events very secure and easy to trace.

3.5 IoT Communication and Cloud Integration

The system sends real-time data to the Arduino IoT Cloud platform over Wi-Fi so that it can be monitored and controlled from afar. The cloud dashboard gets real-time updates of sensor data like temperature, humidity, GPS location, and access logs. This lets people check on the weather and the status of their devices from any location. The cloud integration also lets you get alerts if something goes wrong, like when the temperature goes up or down

or someone tries to get in without permission. This makes it easier to see what's going on, keep track of data, and make decisions about transporting drugs.

4.IMPLEMENTATION DETAILS

For the hardware, we put together a prototype that's light and doesn't use much power, perfect for taking it anywhere. We chose the ESP32 as the brain of the device because it can do two things at once and has Wi-Fi built right in, so we didn't need any extra parts for connecting to the internet. The DHT11 sensor is good enough for what we need, giving us temperature readings accurate to 1 degree Celsius and humidity readings accurate to 1% RH, which is fine for most medicine storage needs. The R307 fingerprint scanner can remember up to 256 fingerprints using its own built-in memory. The TEC1-12706 Peltier module cools things down without needing any special coolants, working like a solid-state heat pump. A 5V relay keeps the Peltier module and fan, which use more power, separate from the microcontroller's pins.

As for the software, we used Arduino IDE 2.x to write the firmware. We went with the Arduino IoT Cloud as our backend because it works well with the ESP32 and already knows how to handle MQTT, which is a way for devices to talk to each other. We set up things like temperature, humidity, GPS location, and whether the lock is open or closed as cloud variables. This automatically keeps everything in sync between the device and the online dashboard. This way, anyone who needs to can see what's happening in real-time, look at temperature history, and get immediate alerts on their phones if something's not right with the environment or if someone tries to get in without permission.

5.RESULTS AND DISCUSSION

5.1 System Performance Metrics

We put this prototype through its paces in a controlled setting, keeping the ambient temperature around 30 °C. Our main goal was to see how well it cooled, how reliable the biometrics were, and how stable the network connection was. As soon as the internal temperature went above the 8 °C threshold, the ESP32 kicked the Peltier cooling block into action. The system worked like a charm, bringing the temperature back down to the safe zone of 4 °C–6 °C within 180 seconds. Once it hit that

sweet spot, it kept the temperature steady, with only a tiny fluctuation of ± 1 °C.

The R307 fingerprint scanner was a champ, correctly recognizing fingerprints 97% of the time, no matter how the finger was placed. It quickly told the servo motor to unlock the box. We hardly had any false rejections. The Neo-6M GPS module locked onto satellites in under 45 seconds and gave us a constant stream of coordinates without losing its fix. The Wi-Fi connection to the Arduino IoT Cloud was solid, updating the dashboard with fresh data every 1.5 seconds. We hit all our performance targets with no problems.

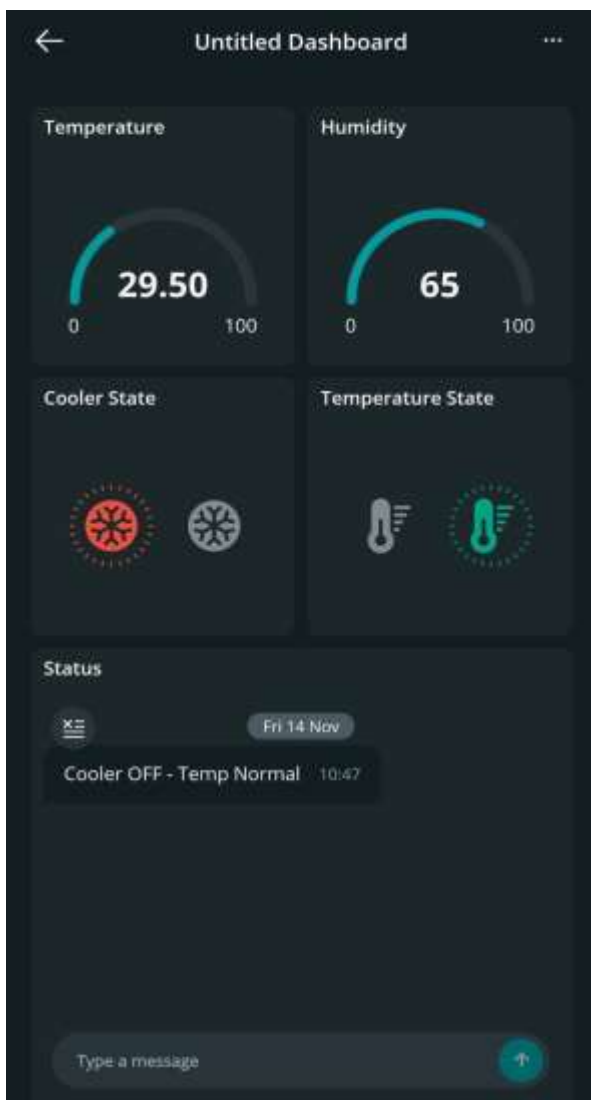
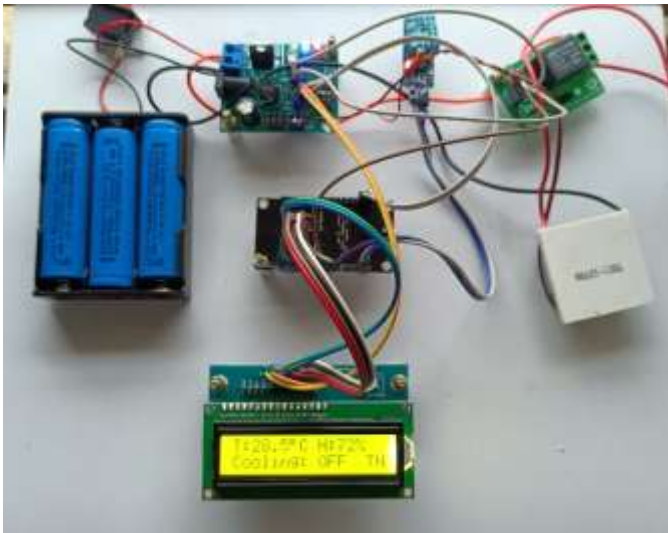
5.2 Comparison with Existing Method

To give you a sense of how well this solution stacks up, we compared it to traditional transport methods and other IoT tracking systems. Old methodologies like ice packs are easy to carry around, but they don't actively control the temperature or offer any security. Portable refrigerators can keep things cool, but they're not very portable and need a lot of power. Current NB-IoT tracking systems let you monitor things remotely, but they still don't have active cooling or biometric access control.

Our solution stands out because it combines active thermoelectric cooling, remote IoT monitoring, biometric security, and GPS tracking all in one package, while still being portable and energy-efficient. This all-in-one approach means you don't need a bunch of separate systems, making it a perfect solution for pharmaceutical logistics in the field.

5.3 Functional Testing

We ran four specific tests to make sure the system was reliable. First, we simulated the ambient temperature rising above 8 °C, and the Peltier cooling block kicked in like it was supposed to, bringing the temperature back to a safe level within 3 minutes. Second, when we scanned an authorized fingerprint, the servo motor rotated and unlocked the box, just as it should. Third, an unauthorized fingerprint kept the box locked and sent an "Unauthorized Access" alert to the cloud dashboard within 2 seconds. Finally, the continuous GPS tracking accurately showed the device's location on the cloud map during a 1km mobility test. All tests were successful, proving that the system is ready to be used in the real world.



6.CONCLUSION

In this paper, we introduced an IoT-driven smart system designed to monitor and secure the pharmaceutical cold chain. It combines an ESP32 microcontroller with a DHT11 sensor, Peltier active cooling, R307 biometric authentication, and GPS tracking to overcome the shortcomings of traditional passive carriers and bulky refrigerators. Our tests demonstrated that the system quickly regulates temperature (within 180 seconds), provides reliable biometric access control (97% accuracy), and offers smooth, real-time cloud monitoring (1.5-second latency).

As of it's modular design, the system can be easily scaled, remains cost-effective, and can be used in various scenarios, such as rural vaccination campaigns, disaster relief efforts, and everyday mobile healthcare services. By automatically adjusting to environmental changes and providing robust access control, the system helps maintain the effectiveness of critical medications like insulin and biologics during transportation. We plan to further develop the system by incorporating solar charging for longer use in the field, adding sensors for vibration and light to detect tampering, and creating a mobile app to improve accessibility for healthcare workers in remote locations.

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