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Secure Cold-Chain Medicine Transportation Using IoT Sensors, Mobile Fingerprint Authentication, and Evaporative Mist Cooling

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ABSTRACT: The transportation of temperature-sensitive medicines and vaccines requires continuous monitoring, secure communication, and controlled access to prevent spoilage, tampering, and unauthorized handling. This project presents an enhanced IoT-based smart medicine transport and monitoring system integrated with Bluetooth-enabled biometric authentication using mobile fingerprint verification. The proposed system combines temperature and GPS sensors, Arduino-based smart cooling container, MQTT communication, CRC-32 data integrity mechanism, and elliptic curve cryptography for secure data transmission. To further strengthen physical security, a Bluetooth Low Energy (BLE) module is introduced to authenticate the receiver using a mobile application with fingerprint verification before unlocking the smart medicine container. This eliminates the risk of PIN theft, unauthorized access, and human errors during delivery. Real-time monitoring, alert notifications, and encrypted communication ensure the medicine remains within the safe temperature range throughout transit. Experimental analysis shows improved reliability, secure access control, reduced medicine wastage, and enhanced user trust. The proposed system provides a scalable and cost-effective solution for secure cold-chain logistics in healthcare and pharmaceutical supply chains.

Keywords: Internet of Things (IoT), Smart Medicine Transport, Cold Chain Monitoring, Arduino Mega, DHT11 Sensor, DS18B20 Temperature Sensor, Bluetooth Authentication, Mobile Fingerprint Authentication, HC-05 Bluetooth Module, Mist Spray Cooling, Evaporative Cooling, Vaccine Storage Monitoring, Secure Medical Logistics, Environmental Monitoring, Smart Healthcare System, Real-Time Temperature Monitoring, Wireless Sensor Network (WSN), Embedded Systems, Medical Supply Chain, Smart Cold Storage System.

Introduction: The quality of medicines is a prerequisite for safe and effective medical treatment. Ensuring proper storage and handling of pharmaceutical products throughout the entire chain of storage, transport, and use is essential to maintaining their efficacy. In this regard, the incorporation of information and communication technologies (ICT) in healthcare presents an opportunity to enhance care processes while promoting active patient involvement in remote monitoring. It is important to note that patients, as end users, are often directly responsible for storing medications in their homes using available household resources. Furthermore, according to current regulations [1], precise control of the entire cold chain is required for the storage and transport of drugs, including when medications are kept at home until administration. After discharge from the hospital, patients are typically prescribed pharmacological treatments, with hospital pharmacy services dispensing medications to ensure proper dosage adherence. These medications are stored in patients' homes, often using non-medical refrigeration devices. While hospital pharmacists provide guidance on the appropriate storage conditions and potential consequences of improper preservation, several studies [2–4] suggest that out-of-hospital medication quality management can be compromised by various factors. Environmental conditions – particularly temperature excursions, humidity, and exposure to light – can severely affect the stability and efficacy of thermolabile or photosensitive drugs. For example, insulin loses potency when stored outside the temperature range [5]; certain vaccines may become ineffective after brief exposure to ambient temperatures; and some antibiotic suspensions degrade rapidly in humid environments. These risks are especially pronounced in domestic settings, where refrigeration devices are not designed for medical use and may exhibit temperature fluctuations, power failures, or frequent door openings. Moreover, unlike hospitals, patient homes lack continuous monitoring systems that can detect and report deviations in real time. Existing research [6,7] highlights the need for new methods to ensure the integrity of medicines within the hospital cold chain, typically managed by healthcare professionals. However, implementing these protocols becomes challenging when patients are responsible for optimal storage, as medications are stored outside controlled hospital environments. In this context, the development of non-intrusive and user-friendly monitoring systems is crucial to safeguard therapeutic efficacy and reduce health risks associated with degraded pharmaceuticals. Currently, medication quality control during transport between pharmaceutical companies and hospital pharmacy services, as well as within hospital facilities, relies on automated temperature monitoring systems. The same approach has been used to assess thermal profiles in the preservation of thermolabile drugs at patients' homes. Specifically, data loggers record temperature fluctuations during transport and storage, but these commercial meters are typically passive single-use devices, leading to high costs per medication. Additionally, stored data can only be accessed once the device is retrieved and analyzed, preventing real-time corrective actions. Prospective studies [5,8,9] indicate that medications often do not remain within recommended temperature ranges in home settings. Moreover, research [10] has shown that domestic refrigerators frequently exceed 8 ◦C or drop below 2 ◦C, making them unsuitable for pharmaceutical preservation. While several IoT-based solutions have been proposed for monitoring medication storage conditions, these are often limited to centralized environments such as hospital storage rooms or transport containers. A recent review of the literature revealed a lack of platforms that provide decentralized, end-to-end monitoring extending into patients' homes. This gap highlights the need for a more comprehensive and patient-centered approach. In response to these challenges, this work proposes a platform architecture for monitoring medicine conservation beyond hospital facilities, extending into patients' homes by leveraging Internet of Things (IoT) technologies [11].

LITERATURE SURVEY :2.1 K. S. J. Prakash et al. (2020) "IoT Based Smart Cold Chain Management System for Pharmaceutical Products" • Journal: 2020 International Conference on System, Computation, Automation and Networking (ICSCAN) - IEEE Xplore. • What they proposed: They proposed a system for monitoring temperature and humidity using DHT sensors and an Arduino-based architecture. • Key Detail: Similar to your abstract, they focused on the automated cooling intervention. They proposed that when the sensor detects a breach, a cooling unit is triggered, and a GSM module sends an immediate "Alert SMS" to the administrator with the exact GPS coordinates of the vehicle. 2.2. S. Gopinath et al. (2023) "Smart Secure Delivery System using IoT and GSM" • Journal: 2023 International Conference on Signal Processing, Computation and Control (ISPCC) - IEEE Xplore. • What they proposed: They proposed a hardware-secured box for high-value goods that remains locked until a specific condition is met. • Key Detail: This paper specifically covers your OTP/Secure Lock requirement. They proposed that the recipient receives a unique code via SMS (GSM). Only when the keypad on the container receives the correct code does the solenoid lock release. This mirrors your "authorized reply" mechanism for secure delivery. 2.3. P. Singh et al. (2021) "Real-Time Cold Chain Monitoring System for Vaccine Distribution" • Journal: 2021 5th International Conference on Computing Methodologies and Communication (ICCMC) - IEEE Xplore. • What they proposed: They proposed a portable vaccine carrier utilizing a Peltier (Thermoelectric) module for active temperature regulation. • Key Detail: Their proposal includes the use of IoT (Thingspeak) to plot real-time graphs of temperature. They specifically detailed the automatic switching logic for the Peltier module based on threshold values, ensuring that the medicine never leaves the required to range. 2.4. M. Adil et al. (2020) "A Smart IoT Based System for Monitoring and Tracking of Pharmaceutical Products" • Journal: 2020 IEEE International Conference on Smart Cloud (SmartCloud). • What they proposed: They proposed a "Decision Support System" for logistics. • Key Detail: They focused on the Trip Status indicators (Start/End switches). They proposed that the system should log the "Time of Departure" and "Time of Arrival" automatically. Their system utilized an LCD display on the box to show the driver the current internal status, similar to your local monitoring requirement. 2.5 R. Kumar & A. Selvakumar (2022) "Anti-Theft and Environment Sensing Smart Box for Logistics using IoT" • Journal: 2022 IEEE 7th International Conference on Recent Advances and Innovations in Engineering (ICRAIE). • What they proposed: They proposed an integrated smart box that combines environmental sensors with anti-theft security.

Proposed Method:

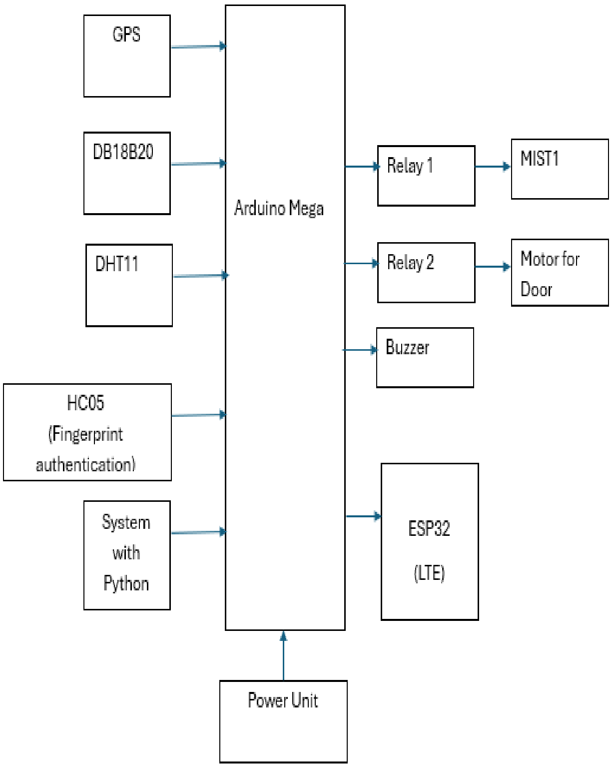

Fig: 1 Proposed Block diagram

The proposed system is designed to monitor medicine transportation, maintain required temperature, and provide secure access using Bluetooth-based mobile fingerprint authentication. The system consists of sensing, control, communication, cloud monitoring, and biometric access modules.

Arduino Mega (Central Controller)

The Arduino Mega acts as the brain of the entire system. It collects data from sensors, processes the information, controls the cooling mechanism, communicates with the cloud through the communication module, and manages Bluetooth authentication for unlocking the medicine container.

Main functions:

Reads temperature sensor values

Controls cooling system (fan/peltier/refrigeration)

Sends data to cloud/mobile app

Receives unlock command after authentication

Controls electronic lock of the container

External Environment Monitoring – DHT11 Sensor

The DHT11 sensor monitors the outside environment during transportation.

Measured parameters:

Ambient temperature

Humidity

Detect harsh environmental conditions during transit

Compare external temperature with internal storage temperature

Generate alerts when external temperature becomes critical

Help in predicting cooling load requirement

Medicine Storage Monitoring – DS18B20 Sensor

The DS18B20 temperature sensor monitors the internal temperature of the medicine storage box.

Purpose:

Ensures medicines remain within safe range (2–8°C)

Sends real-time temperature data to Arduino

Triggers cooling system if temperature goes out of range

Sends alerts to mobile/cloud when abnormal temperature detected

This sensor is the most critical safety component of the system.

HARDWARE COMPONENTS:

ARDUINO MEGA

The Arduino Mega is based on ATmega2560 Microcontroller. The ATmega2560 is an 8-bit microcontroller. We need a simple USB cable to connect to the computer and the AC to DC adapter or battery to get started with it. The Arduino Mega is organized using the Arduino (IDE), which can run on various platforms. Here, IDE stands for Integrated Development Environment.

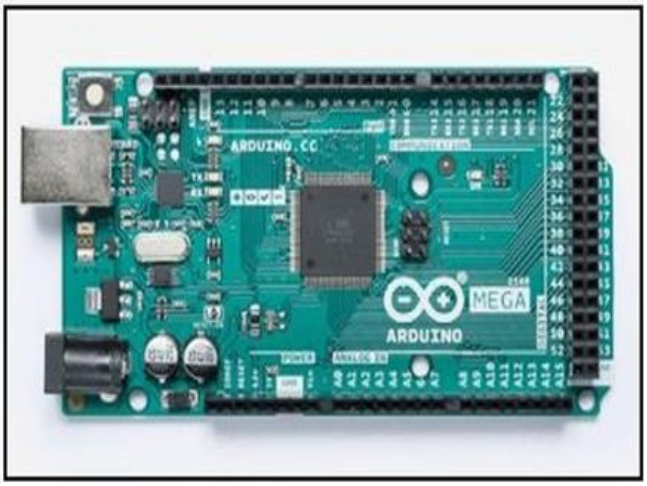

Fig2: Arduino mega module

The functioning of the Arduino Mega is similar to other Arduino Boards. We need not require extra components for its working.

DHT11 for temperature and humidity:

The DHT11 humidity and temperature sensor makes it really easy to add humidity and temperature data to your DIY electronics projects. It's perfect for remote weather stations, home environmental control systems, and farm or garden monitoring systems.

Here are the ranges and accuracy of the DHT11:

Humidity Range: 20-90% RH

Humidity Accuracy: ±5% RH

Temperature Range: 0-50 °C

Temperature Accuracy: ±2% °C

Operating Voltage: 3V to 5.5V

The DHT11 Datasheet:

RELATIVE HUMIDITY

The DHT11 measures relative humidity. Relative humidity is the amount of water vapor in air vs. the saturation point of water vapor in air. At the saturation point, water vapor starts to condense and accumulate on surfaces forming dew. The saturation point changes with air temperature. Cold air can hold less water vapor before it becomes saturated, and hot air can hold more water vapor before it becomes saturated. The formula to calculate relative humidity is:

Relative humidity is expressed as a percentage. At 100% RH, condensation occurs, and at 0% RH, the air is completely dry.

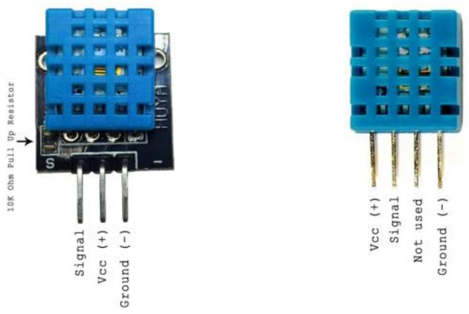

Fig3: DHT11 modules

DS18B20 TEMPERATURE SENSOR:

The digital temperature sensor like DS18B20 follows single wire protocol and it can be used to measure temperature in the range of -67oF to +257oF or -55oC to +125oC with +-5% accuracy. The range of received data from the 1-wire can range from 9-bit to 12-bit. Because, this sensor follows the single wire protocol, and the controlling of this can be done through an only pin of Microcontroller. This is an advanced level protocol, where each sensor can be set with a 64-bit serial code which aids to control numerous sensors using a single pin of the microcontroller. This article discusses an overview of a DS18B20 temperature sensor

The DS18B20 is one type of temperature sensor and it supplies 9-bit to 12-bit readings of temperature. These values show the temperature of a particular device. The communication of this sensor can be done through a one-wire bus protocol which uses one data line to communicate with an inner microprocessor. Additionally, this sensor gets the power supply directly from the data line so that the need for an external power supply can be eliminated. The applications of the DS18B20 temperature sensor include industrial systems, consumer products, systems which are sensitive thermally, thermostatic controls, and thermometers.

Specifications

The specifications of this sensor include the following.

This sensor is a programmable and digital temperature sensor

The communication of this sensor can be done with the help of a 1-Wire method

The range of power supply is 3.0V – 5.5V

Fahrenheit equal s to -67°F to +257°F

The accuracy of this sensor is ±0.5°C

The o/p resolution will range from 9-bit to 12-bit

It changes the 12-bit temperature to digital word within 750 ms time

This sensor can be power-driven from the data line

These are obtainable like SOP, To-92, and also as a waterproof sensor

Working Principle

The working principle of this DS18B20 temperature sensor is like a temperature sensor. The resolution of this sensor ranges from 9-bits to 12-bits. But the default resolution which is used to power-up is 12-bit. This sensor gets power within a low-power inactive condition. The temperature measurement, as well as the conversion of A-to-D, can be done with a convert-T command. The resulting temperature information can be stored within the 2-byte register in the sensor, and after that, this sensor returns to its inactive state. If the sensor is power-driven by an exterior power supply, then the master can provide read time slots next to the Convert T command. The sensor will react by supplying 0 though the temperature change is in the improvement and reacts by supplying 1 though the temperature change is done.

Fig4:Types Of DS18B20 Temperature Sensor

The DS18B20 temperature sensor is fairly precise and does not require any external components to function. It has a temperature range of -55°C to +125°C and an accuracy of ±0.5°C.

The temperature sensor's resolution can be set to 9, 10, 11, or 12 bits. The default resolution at power-up, however, is 12-bit (i.e., 0.0625°C precision).

HC-05 Bluetooth Module:

the HC-05 Bluetooth Module, or the HC-05 Sub Module, to be precise, comes with the BC417 IC along with a flash memory. Such Modules come as surface mount board and several third-party manufacturers use these board to build a more complete system with necessary pins and components. The following image shows one such HC-05 Bluetooth Sub Module (the green board mounted on the blue board) being used as a part of a complete Bluetooth Module.

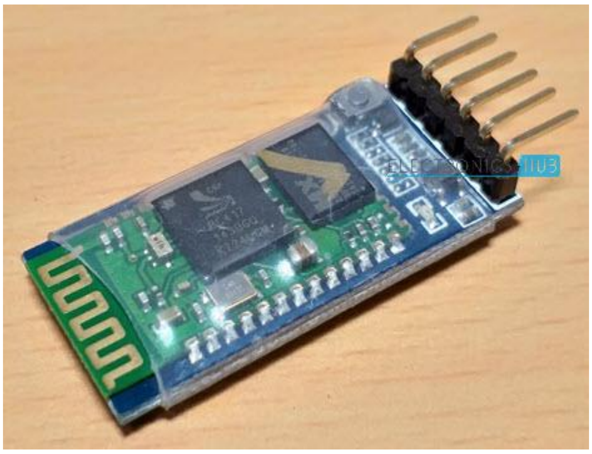

Fig5: Pins of HC-05 Bluetooth Module

The HC-05 Module supports for UART, USB as well as SPI communication and depending on the application, necessary pins can be used. In my case, the board uses the UART communication. Coming to the pins of the Bluetooth Module, generally, four pins are sufficient for successfully enabling a wireless communication link but the modules produced now-a-days come with six pins namely: VCC, GND, TX, RX, EN and STATE.

RESULTS:

The implemented system successfully demonstrated:

✓ Continuous monitoring of medicine temperature

✓ Real-time cloud tracking using MQTT

✓ Instant alerts during emergencies

✓ Secure biometric access control

✓ Reliable operation under transport conditions

The experimental results confirm that the system can significantly reduce medicine spoilage, theft, and logistics risks.

Total system reaction time < 6 seconds, which is suitable for real-world logistics.

Table 1: Response time

Event	Response Time
Temperature threshold detection	2 sec
MQTT update	2 sec
SMS alert	5–6 sec
Authentication response	3 sec

ADVANTAGES:

Security Advantages

• Dual-layer security using ECC encryption + CRC-32 integrity

• New biometric authentication prevents unauthorized access

• Eliminates risk of PIN sharing or leakage

• Secure Bluetooth pairing prevents remote attacks

• End-to-end encrypted communication via MQTT

Operational Advantages

• Real-time temperature and GPS monitoring

• Automatic temperature regulation during transit

• Instant alerts on abnormal conditions

• Remote monitoring through mobile app

• Data logging for compliance and auditing

Economic Advantages

• Reduces medicine and vaccine wastage

• Prevents financial losses in pharma supply chain

• Low-cost hardware implementation

• Energy efficient and suitable for IoT devices

User Advantages

• Easy mobile-based unlocking using fingerprint

• Faster delivery verification process

• No technical expertise required to operate

• Transparent tracking for sender and receiver

APPLICATIONS:

Healthcare & Pharma

• Vaccine cold-chain transportation
• Insulin and temperature-sensitive drugs delivery
• Blood and organ transportation monitoring
• Hospital-to-hospital medicine logistics

Smart Logistics

• Pharmaceutical supply chain management
• Secure courier services for medical packages
• High-value product transportation

Emergency & Remote Healthcare

• Rural medicine delivery monitoring
• Disaster relief medical supply transport
• Drone-based medicine delivery (future integration)

Government & Defense

• Military medical supply logistics
• Disaster management medical kits transport

CONCLUSION This project presents a secure and intelligent IoT-based medicine transportation system enhanced with Bluetooth-enabled biometric authentication. The integration of temperature monitoring, GPS tracking, encrypted communication, and fingerprint-based container access provides a comprehensive solution to address the challenges of medicine spoilage, unauthorized access, and lack of transparency in the pharmaceutical supply chain. The addition of mobile fingerprint authentication significantly improves the physical security of the medicine container by ensuring that only the authorized receiver can unlock it. The use of lightweight cryptographic techniques such as ECDH, AES-256, and CRC-32 ensures data confidentiality, integrity, and efficient performance on low-power IoT devices. Overall, the system demonstrates improved reliability, enhanced security, reduced medicine wastage, and increased trust among stakeholders. The proposed solution has strong potential for real-world deployment in smart healthcare logistics.

FUTURE SCOPE

Technology Enhancements

• Integration of Blockchain for tamper-proof shipment logs
• AI-based temperature prediction and anomaly detection
• Integration with 5G for faster real-time communication
• Edge-AI for smart decision making inside container

Security Improvements

• Multi-factor authentication (Face + Fingerprint + OTP)
• Anti-tamper sensors for theft detection
• Zero-trust architecture for IoT devices

Hardware Improvements

• Solar-powered smart medicine container
• Smaller and more energy-efficient hardware
• Integration with drone delivery systems

System Expansion

• Cloud analytics dashboard for hospitals and pharma companies
• Large-scale deployment for national vaccine distribution
• Integration with smart hospital systems and e-health records

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