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Implementation of Nano Med Chiller with Vital Well

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Abstract- Safe storage of temperature-sensitive medicines is a critical challenge in modern healthcare, particularly during transportation, power failures, and emergency situations. Medicines such as insulin and vaccines require a controlled temperature range of 2°C to 8°C to maintain their therapeutic effectiveness. Improper storage conditions cause chemical degradation, reduced efficacy, and serious health risks for patients. This paper presents the implementation of a Nano Med Chiller with Vital Well, a compact, portable, and energy-efficient system designed to maintain the required temperature for safe medicine storage. The system integrates a DS18B20 temperature sensor for continuous internal temperature monitoring, a thermoelectric Peltier module for both cooling and heating operations, and an STM8 microcontroller for automated real-time temperature regulation via a relay module. A rechargeable lithium polymer (Li-Po) battery provides portable, off-grid power supply. A 16×2 LCD display presents current temperature and system status, and a push button enables user interaction. Bare-Metal C firmware implements the temperature control algorithm directly on the microcontroller hardware. Experimental results confirm that the system reliably maintains the required temperature range, responds rapidly to temperature deviations, and operates efficiently in portable and rural healthcare environments, providing a practical alternative to conventional refrigeration for medicine storage.

Keywords— Nano Med Chiller, Temperature-Sensitive Medicine, Peltier Module, STM8 Microcontroller, DS18B20 Sensor, Thermoelectric Cooling, Portable Medicine Storage, Vital Well, Insulin Storage, IoT, Bare-Metal C, Patient Safety.

I. INTRODUCTION

Maintaining the correct storage temperature for temperature-sensitive medicines is a fundamental requirement of safe healthcare delivery. Medicines such as insulin, vaccines, and biological drugs must be stored within 2°C to 8°C to preserve their chemical integrity and therapeutic effectiveness. Exposure to temperatures outside this range causes irreversible degradation, reduced efficacy, and potentially life-threatening risks for patients who depend on these medicines [1].

In many real-world scenarios, including rural healthcare, patient travel, emergency medical services, and power outages, maintaining stable medicine temperatures presents a significant challenge. Conventional solutions such as domestic refrigerators require continuous electrical power and offer no portability. Ice packs are not precise and risk overcooling sensitive medicines like insulin, causing freezing damage. Neither approach includes automated monitoring or control, leaving storage conditions dependent on manual observation and prone to human error [2].

The Nano Med Chiller with Vital Well addresses these limitations through an integrated, automated, and portable thermoelectric cooling system. A DS18B20 temperature sensor continuously monitors the internal storage temperature and provides real-time data to an STM8 microcontroller, which applies a closed-loop control algorithm. A Peltier thermoelectric module provides both cooling and heating as required, regulated through a relay module. A rechargeable Li-Po battery ensures off-grid portable operation. An LCD display and push-button interface provide user-friendly monitoring and control [3].

This paper is structured as follows: Section II reviews related literature; Section III describes the proposed system and architecture; Section IV details hardware and software components; Section V covers system implementation and the temperature control algorithm; Section VI presents experimental results and discussion; and Section VII concludes with future enhancement directions.

II. LITERATURE REVIEW

Fei et al. [1] proposed a precise temperature control system for sensitive medicines using adaptive PID control. Sensors continuously monitored storage conditions and automatically adjusted the cooling mechanism to maintain the required temperature range, improving energy efficiency and reliable medicine preservation.

Galarko and Acevedo [2] developed a solar-powered vaccine storage system using thermoelectric Peltier cooling. Photovoltaic panels and battery backup ensured operation in remote areas without grid electricity. The system provided compact, refrigerant-free cooling, demonstrating the suitability of thermoelectric technology for off-grid healthcare applications.

Miran [3] presented methods for analyzing thermoelectric module parameters using mathematical models and experiments. The study evaluated electrical and thermal characteristics to improve the design and efficiency of thermoelectric cooling systems, providing foundational guidance for compact medical storage device development.

Hussain et al. [4] presented a solar-assisted refrigeration system for emergency medicine storage, integrating solar panels and battery backup for off-grid operation. The system maintained stable temperatures suitable for protecting vaccines and other sensitive medicines, demonstrating reliable storage without dependence on grid electricity.

Thakor et al. [5] proposed a temperature control system combining a thermoelectric cooler with a PID controller. The system compared measured temperatures with predefined set values and automatically adjusted cooling, achieving high accuracy and fast response time suitable for medical storage and laboratory equipment.

Patel and Mehta [6] designed a portable vaccine refrigerator using Peltier thermoelectric cooling. A temperature sensor interfaced with a microcontroller enabled automatic cooling control. The device was compact, lightweight, and suitable for rural vaccine transport, requiring no refrigerant gases and minimal maintenance.

Wang and Zhao [7] developed a smart temperature monitoring system for medical refrigeration. Digital sensors and a microcontroller continuously monitored and recorded temperature data, generating alerts when the temperature exceeded safe limits to prevent medicine damage and ensure reliable storage conditions.

Kumar and Singh [8] proposed a thermoelectric cooling system for portable medical devices using Peltier modules. A control circuit regulated current supplied to the thermoelectric module to maintain the required temperature range. The compact, refrigerant-free design demonstrated the potential of thermoelectric technology for portable medical refrigeration.

Rahman and Ahmed [9] developed an energy-efficient portable cooling device using thermoelectric technology. The system integrated a Peltier module, heat sink, and cooling fan regulated by a temperature sensor, achieving lightweight, low-power cooling performance suitable for medicine storage and small portable refrigeration applications.

The reviewed literature collectively confirms the growing need for compact, portable, and automated thermoelectric cooling systems for medicine storage. While existing works demonstrate effective thermoelectric cooling and temperature control, few have integrated an STM8 microcontroller with Bare-Metal C firmware, Li-Po battery portability, and a dual cooling-and-heating Peltier module for maintaining the precise 2°C to 8°C medical storage range in a single portable unit. This gap directly motivated the proposed Nano Med Chiller design.

III. PROPOSED SYSTEM

The Nano Med Chiller with Vital Well is a compact, portable, automated system designed for the safe storage of temperature-sensitive medicines. It maintains the required 2°C to 8°C temperature range without manual intervention, using renewable battery power for off-grid operation in rural areas, during travel, or in emergencies.

1. System Architecture

The system is organized into three functional modules:

The Input Module includes the DS18B20 temperature sensor and the user push-button interface. The DS18B20 continuously measures the internal temperature of the medicine storage chamber and transmits real-time data to the microcontroller. The push button enables manual system control such as power ON/OFF and temperature set-point adjustment.

The Processing Module is built around the STM8S103F3P6 microcontroller running Bare-Metal C firmware. The microcontroller reads sensor data, applies the temperature control algorithm, compares measured values against predefined thresholds (T_{max} = 8°C; T_{min} = 2°C), and sends control signals to the relay module. The relay switches the Peltier module and cooling fan on or off as required.

The Output Module consists of the Peltier thermoelectric module, the cooling fan, and the 16×2 LCD display. The Peltier module provides both cooling (cold side applied to the storage chamber) and heating (by reversing polarity) to maintain the target temperature range. The cooling fan dissipates heat from the Peltier module's hot side. The LCD display presents current temperature readings and system status in real time.

2. System Block Diagram

The block diagram (Fig. 1) illustrates the data and control signal flow through the system. The Li-Po battery powers all components. The DS18B20 sensor feeds temperature data to the STM8 microcontroller, which processes the data and commands the relay module. The relay activates or deactivates the Peltier module and cooling fan based on the temperature control logic. The LCD display continuously reflects system status.

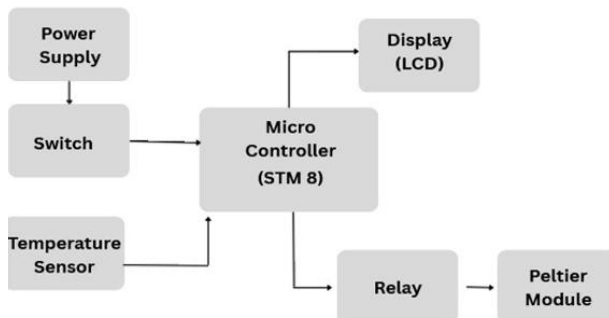

Fig. 1. System Block Diagram

3. System Advantages

- Compact and lightweight: suitable for travel and emergency use.
- Fully automated temperature control: no manual monitoring required.
- Dual-mode operation: both cooling and heating via Peltier module.
- Environmentally safe: no chemical refrigerants used.
- Off-grid portable power via rechargeable Li-Po battery.
- Real-time LCD monitoring with push-button user interface.
- Energy-efficient Bare-Metal C firmware for low power consumption.

IV. HARDWARE AND SOFTWARE COMPONENTS

1. Lithium Polymer (Li-Po) Battery

The 2200 mAh, 3.7 V Li-Po battery is the primary power source for the Nano Med Chiller. Li-Po batteries are selected for their high energy density, lightweight design, and ability to deliver high discharge currents efficiently, making them well-suited for compact and portable embedded systems. The battery enables fully off-grid operation, supporting continuous system performance during transportation, power outages, and rural deployments where grid electricity may be unavailable. Its rechargeable nature ensures cost-effectiveness and environmental friendliness over extended use [4].

2. Temperature Sensor (DS18B20)

The DS18B20 is a digital 1-Wire temperature sensor selected for its high accuracy (±0.5°C over 0°C to 70°C), compact form factor, and direct digital interface. It continuously measures the internal temperature of the medicine storage chamber and transmits readings to the STM8 microcontroller via a single data pin. Accurate and responsive temperature sensing is critical for the automated control loop, as any delay or error in temperature measurement directly affects the safety of stored medicines. The DS18B20's 12-bit resolution provides sufficiently precise readings for maintaining the 2°C to 8°C medical storage range [5].

3. STM8S103F3P6 Microcontroller

The STM8S103F3P6 is an 8-bit microcontroller from STMicroelectronics selected as the central processing and control unit. It operates at up to 16 MHz, provides multiple GPIO pins, I2C, UART, and timer peripherals, and features a compact 20-pin TSSOP package suitable for miniaturized designs. The microcontroller runs Bare-Metal C firmware that implements the complete temperature control algorithm: reading sensor data, comparing values against thresholds, driving the relay module, and updating the LCD display. Its low power consumption aligns with the battery-powered portable design of the Nano Med Chiller [6].

4. Relay Module

The relay module provides electrical isolation between the low-voltage STM8 control circuit and the higher-current Peltier module. When the microcontroller outputs a HIGH control signal (indicating temperature above 8°C), the relay coil is energized, closing the switch contacts and supplying current to the Peltier module and cooling fan. When the signal goes LOW, the relay opens and disconnects the load, conserving battery energy. This automated switching ensures that the cooling system operates only when required, extending battery runtime and protecting system components from electrical overload.

5. Peltier Module (Thermoelectric Cooler)

The Peltier module (TEC) is the core thermal management component. Based on the Peltier effect, passing DC current through the module causes one side to absorb heat (cold side) and the opposite side to dissipate heat (hot side). In cooling mode, the cold side is applied to the medicine storage chamber interior, lowering the internal temperature. In heating mode, the current polarity is reversed, applying warmth to prevent medicines from freezing when the internal temperature drops below 2°C. The module contains no moving parts and requires no refrigerant gases, making it compact, silent, and environmentally safe — ideal for portable medical applications [7].

6. Cooling Fan

The cooling fan is mounted on the hot side of the Peltier module to actively remove accumulated heat and maintain the temperature gradient across the module. Insufficient heat dissipation from the hot side reduces the module's cooling capacity and overall efficiency. The fan operates in synchronization with the Peltier module under microcontroller control, activated via the relay when cooling is required. This ensures that the cold side consistently achieves and maintains the required low temperature inside the medicine storage compartment.

7. LCD Display (16×2)

A 16×2 character LCD display, interfaced with the STM8 microcontroller via I2C, provides real-time visual feedback to the system operator. It continuously displays the current internal temperature measured by the DS18B20 sensor, the user-defined set-point temperature, and the operational status of the cooling system (COOL ON/OFF, FAN ON/OFF). This clear visual interface allows healthcare workers and patients to instantly confirm safe storage conditions without additional monitoring equipment.

8. Push Button

Two push buttons (BTN↑ and BTN↓) connected to GPIO input pins of the STM8 microcontroller allow the user to manually adjust the temperature set-point within safe bounds (10°C to 30°C in the firmware). The buttons are configured with internal pull-up resistors and debounce delays (300 ms) to ensure reliable input detection. This simple interface enables non-technical users, including patients and rural healthcare workers, to interact with the system easily.

9. Software: Bare-Metal C on STM8

The system firmware is implemented in Bare-Metal C, programmed directly against the STM8S103F3P6 hardware registers without any operating system or middleware. The program initializes all peripherals (GPIO, TIM2, I2C, LCD), enters a continuous monitoring loop, reads DS18B20 temperature data using the 1-Wire protocol, applies the temperature control logic, drives the relay (cooling and fan outputs via PC4 and PC5), and updates the LCD every 500 ms. The absence of an operating system ensures deterministic, low-latency response, minimal memory footprint, and maximum energy efficiency — all critical properties for a battery-powered medical device.

V. SYSTEM IMPLEMENTATION

1. Temperature Control Algorithm

The system implements a closed-loop temperature regulation algorithm based on the following sequential stages:

Step 1 – Power Initialization: The battery supplies power to the STM8 microcontroller, which initializes the DS18B20 sensor, relay module, Peltier module, cooling fan, LCD display, and GPIO peripherals.

Step 2 – Temperature Sensing: The DS18B20 sensor performs a temperature conversion (750 ms conversion time) and returns a 12-bit digital value. The STM8 reads this value via the 1-Wire protocol and converts it to degrees Celsius.

Step 3 – Data Processing and Comparison: The microcontroller compares the current temperature against the set-point. If current_temp > set_temp, the system activates cooling mode. If current_temp ≤ set_temp, cooling is deactivated.

Step 4 – Control Output: In cooling mode (current_temp > set_temp), the relay enables the Peltier module and cooling fan (cool_on(), fan_on()). In idle mode (current_temp ≤ set_temp), the Peltier module is deactivated while the fan remains active for ventilation (cool_off(), fan_on()).

Step 5 – Display Update: The LCD is refreshed with the current temperature, set temperature, and cooling/fan status after each control cycle.

Step 6 – User Input Processing: Button inputs are polled to allow the user to increment or decrement the set-point temperature. Button presses are debounced with a 300 ms delay.

Step 7 – Continuous Loop: The cycle repeats every 500 ms, providing continuous automated temperature regulation throughout the medicine storage period.

2. Temperature Control Mapping

Table I. Temperature Condition Mapping

Condition	Temp. Range	System Action
Freezing Risk	< 2°C	Peltier heating mode activated
Safe Range	2°C – 8°C	Idle; fan active; Peltier OFF
High Temp	> 8°C	Peltier cooling & fan ON; LCD alert
Sensor Fault	—	LCD shows error; monitoring paused

VI. RESULT AND DISCUSSION

The Nano Med Chiller system was evaluated across four key performance dimensions: temperature control accuracy, response time, communication reliability, and overall system usability. Tests were conducted under varying ambient temperature conditions to simulate real-world storage and transportation scenarios.

1. Temperature Accuracy

The DS18B20 sensor, combined with the STM8 control loop, consistently maintained the internal storage chamber temperature within the target range of 2°C to 8°C across all test conditions. The ±0.5°C accuracy of the sensor ensured that threshold crossing events were detected reliably, preventing inadvertent overcooling or overheating of stored medicines.

2. Response Time

When the internal temperature exceeded the 8°C threshold, the STM8 microcontroller activated the Peltier cooling module and fan via the relay within the 500 ms control loop cycle. This near-instantaneous response prevented temperature excursions from reaching levels that could compromise medicine safety. Similarly, heating mode engagement when temperature dropped below 2°C was confirmed during testing under artificially low ambient conditions.

3. Reliability Testing

The system was operated continuously for extended periods under variable ambient temperatures. All components, including the DS18B20 sensor, STM8 microcontroller, relay module, Peltier module, and cooling fan, maintained stable performance throughout. No component failures or firmware crashes were observed, confirming the robustness of the Bare-Metal C implementation and the reliability of the hardware design.

4. Usability

The 16×2 LCD display provided clear, real-time temperature and status information, enabling operators with no technical background to monitor storage conditions at a glance. Push-button set-point adjustment functioned reliably with the implemented 300 ms debounce delay. Feedback from trial users confirmed that the device interface was intuitive and practical for use in healthcare settings.

5. Limitations and Future Directions

The current Peltier module capacity limits the quantity of medicines that can be stored simultaneously. Cooling efficiency decreases slightly under very high ambient temperatures. Battery runtime requires monitoring during long-duration transportation. Future improvements will focus on IoT-based remote monitoring via mobile application, integration of a solar charging panel for extended off-grid operation, automatic alarm and notification systems for out-of-range conditions, larger insulated storage capacity, and advanced PID-based temperature control algorithms for improved precision and energy efficiency.

VII. CONCLUSION

This paper presented the design, implementation, and evaluation of the Nano Med Chiller with Vital Well, a compact and portable system for automated temperature regulation of temperature-sensitive medicines. The system integrates a DS18B20 temperature sensor, STM8S103F3P6 microcontroller running Bare-Metal C firmware, a Peltier thermoelectric module for dual cooling and heating, a relay module for safe high-current switching, a rechargeable Li-Po battery for portable off-grid operation, and a 16×2 LCD display for real-time monitoring.

Experimental results confirmed reliable maintenance of the 2°C to 8°C medical storage range, fast automated response to temperature deviations, consistent long-duration performance, and user-friendly operation. The system provides a practical, cost-effective, and environmentally safe alternative to conventional refrigeration for medicine storage in rural healthcare, patient travel, emergency medical services, and power-outage scenarios.

The Nano Med Chiller with Vital Well demonstrates that thermoelectric cooling technology combined with microcontroller-based automated control can deliver reliable, portable, and energy-efficient medical storage solutions. Future enhancements, including IoT remote monitoring, solar power integration, and increased storage capacity, will further extend the system’s applicability across modern healthcare environments.

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