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Thermal Equilibrium Time Study Apparatus Using Arduino

Aditya Murlidhar Wanaskar[1], Kunal Subhash Narote[2], Mr. Nitesh Hirulkar[3]
[1, 2]B.E Student, Mechanical Engineering, D Y Patil College of Engineering, Akurdi, Pune
[3]Assistant Professor, Mechanical Engineering, D Y Patil College of Engineering, Akurdi, Pune

***Abstract:** Knowing how heat passes from one object to another is an important aspect of learning about physics, and the concept of thermal equilibrium, where two bodies reach the same temperature and do not exchange heat anymore. We designed a basic and cost-efficient thermal equilibrium laboratory setup using an Arduino to simplify this concept in order to better observe and conduct research on it. The main objective of this project is to create a practical learning device that demonstrates thermal equilibrium in real time. This may be helpful in school labs or small experiments to demonstrate to students how heat moves and levels off between two objects. In this setup, two temperature sensors are connected to an Arduino microcontroller. The sensors are placed on two objects of different initial temperatures. The Arduino reads and compares the temperatures continuously. When the temperatures are equal or very close, the Arduino turns on an LED light to indicate that thermal equilibrium has been reached. This technique makes the observation and study of thermal equilibrium easy by removing the requirement for complicated equipment. The use of Arduino provides flexibility, automation, and real-time monitoring. In general, the concept brings together fundamental physics and simple electronics to make a helpful and informative device.*
***Keywords:** Thermal equilibrium, Heat transfer, Temperature sensors, Real-time monitoring, Educational tool*

I. INTRODUCTION AND BACKGROUND

Thermal equilibrium is an elementary physics principle explaining how heat is transferred among objects. When two objects of differing temperatures are brought in contact, heat flows from the warmer to the cooler. This process continues until both objects reach an equal temperature, which is termed as thermal equilibrium. It is important to comprehend this process for research and engineering purposes but challenging to observe directly without proper equipment. This project was developed in an effort to render the process of studying thermal equilibrium easier and interactive, especially to beginners and students. We intend to come up with a device that can be simple but yet display in real time when two objects have attained equal temperature. In achieving this, we utilized an Arduino microcontroller and two temperature sensors. Both of these sensors are mounted on the two objects, and the Arduino reads and compares their temperatures continuously. When the temperatures are the same or very close, the Arduino lights an LED to signal that thermal equilibrium has been achieved. The main aim of this project Is to develop an inexpensive, user-friendly device that makes it easy for students to visualize and comprehend heat transfer. The project is a good teaching aid in classrooms and small laboratories as it links fundamental electronics with the fundamental science concept. It also facilitates hands-on learning and instructs users on basic coding and sensor-based automation.

A. Introduction Literature Review

To gain more insight into the background and refine the design of our thermal equilibrium experiment setup, we went through existing literature and comparable projects. The intention of this literature review was to examine how others approached the concept of thermal equilibrium, what technology and equipment they used, and the application of Arduino or similar microcontrollers in school-level experiments concerning heat transfer. We began by searching for appropriate papers, articles, and project reports from well-known sites such as Google Scholar, IEEE Xplore, ScienceDirect, and Arduino forums. The keywords used to search were “thermal equilibrium experiment,” “heat transfer with Arduino,” “temperature sensor projects,” and “Arduino science projects.” In order to render the review precise and applicable, we had specific criteria to pick studies: The article or project must incorporate temperature readings or thermal tests. It was required to employ Arduino or an equivalent microcontroller platform. It needed to be informative, cheap, or be for small-scale research. We selected around ten out of more than 30 which best served our project objectives. They included academic research journals and well-documented DIY projects.
We cross-compared their purpose, sensors (e.g., thermistors and DS18B20), ways of recording temperature differences, and ways of showing thermal equilibrium. We did not perform any rigorous statistical analysis, but we did tabulate the results in a simple

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comparison table, recording the strengths, limitations, and concepts we could employ or enhance in our own device. This serves to inform decisions like which sensor to employ, how to establish when equilibrium is reached (for instance, a temperature difference of less than 0.5°C), and how to make the system more user-friendly. In summary, the literature review helped us to better comprehend current methodologies and create a more efficient and practical version of a thermal equilibrium study tool using Arduino. It revealed that although numerous similar projects are available, few are designed specifically for classroom use with real-time feedback, like LEDs, which our project is centered around.

II. METHODOLOGY

The procedure of developing the Thermal Equilibrium Study Apparatus with Arduino includes selecting appropriate hardware parts and integrating them, designing and assembling the schematic, developing the software for control and observation, and finally adjusting and verifying the instrument to ensure its accuracy. Locating two thermal bodies achieving equilibrium, and illuminating an LED as a visual indicator.

A. Components Used

The components listed below were chosen for their reliability, compatibility, and simplicity of integration :

- Arduino Uno – Microcontroller board used as the central processing unit.
- DS18B20 Temperature Sensors (x2) – Digital sensors to measure the temperature of both bodies.
- Resistors (4.7k Ohm) – For pull-up configuration with DS18B20 sensors.
- LED – Indicator that lights up when equilibrium is reached.
- Breadboard and Jumper Wires – For prototyping the circuit.
- Power Supply – To power the Arduino and sensors.

B. Circuit Design and Assembly

The circuit was designed to connect two DS18B20 temperature sensors to the Arduino Uno via the One-Wire protocol. Each sensor's data pin was connected to a separate digital input pin on the Arduino using a common ground and power wire. A 4.7k Ohm pull-up resistor was placed between the data pin of each sensor and VCC to ensure proper communication. The LED was connected to an Arduino digital output pin via a current-limiting resistor. The connections were Initially tested on a breadboard to allow for flexibility during prototyping. The circuit was transferred to a PCB for a more permanent configuration after its functionality was verified.

C. Software Development

The software was developed using the Arduino IDE. The following are the primary goals of the code:

- Setting up the temperature sensors using the DallasTemperature and OneWire libraries.
- Continuously taking temperature readings from both sensors.
- Comparison of temperatures in real time.
- The LED output turns on when the absolute difference between the two temperatures falls below a preset threshold (for example, ±0.2°C), which denotes thermal equilibrium.
- The code's modular design made it simple to modify the threshold and sensor reaction time.

D. Code

```
#include <LCD_I2C.h>
LCD_I2C lcd(0x27, 16, 2);

Const int buzzer = 7;
Unsigned long previous_time = 0;
Unsigned long seconds = 0;

Void setup() {
  Lcd.begin();
  Lcd.backlight();
```

```
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  pinMode(9, OUTPUT);
  pinMode(10, OUTPUT);
  pinMode(buzzer, OUTPUT);
  Serial.begin(9600);
}

Void loop() {
  Unsigned long current_time = millis();

  If ((current_time – previous_time) >= 1000) {
    Seconds++;
    Previous_time = current_time;

    Float temp1 = analogRead(A0) * 5.0 / 1024.0;
    Temp1 = (temp1 – 0.5) * 100;

    Float temp2 = analogRead(A1) * 5.0 / 1024.0;
    Temp2 = (temp2 – 0.5) * 100;

    Serial.print("Temperature1 = ");
    Serial.println(temp1);
    Serial.print("Temperature2 = ");
    Serial.println(temp2);

    If (abs(temp1 – temp2) > 0.5) {  // Allow small tolerance
      digitalWrite(10, LOW);
      digitalWrite(9, HIGH);
      noTone(buzzer);
    } else {
      digitalWrite(10, HIGH);
      digitalWrite(9, LOW);
      tone(buzzer, 1000);
    }

    Lcd.setCursor(0, 0);
    Lcd.print("T1=");
    Lcd.print(temp1, 1);
    Lcd.setCursor(0, 1);
    Lcd.print("T2=");
    Lcd.print(temp2, 1);
    Lcd.setCursor(9, 0);
    Lcd.print("Time(S)");
    Lcd.setCursor(11, 1);
    Lcd.print(seconds);
  }
}
```

E. Testing and Calibration

The apparatus was tested using two water-filled containers initially set at different temperatures. The sensors were immersed in each container, and temperature readings were monitored via the Arduino serial monitor. Calibration involved:

- Verifying sensor accuracy using a laboratory-grade thermometer.
- Adjusting the threshold value for equilibrium detection to account for minor sensor fluctuations.
- Ensuring consistent LED triggering at equilibrium across multiple test runs.
- Several test cycles were conducted to validate the stability and repeatability of the system.

III. RESULTS AND DISCUSSION

A. *Experimental Setup*

Two identical containers were filled with water at varying temperatures in order to assess how well the thermal equilibrium study device performed. An Arduino Uno was used to interact with DS18B20 digital temperature sensors that were submerged in each container. When the temperature differential between the two containers dropped below ±0.2°C, a sign of thermal equilibrium, the LED was set to turn on.

B. Experimental Results

The apparatus was tested under varying initial temperature differences. The results from selected trials are summarized in Table 1:

Table 1: Temperature Readings and LED Triggering

Trial	Initial Temperature of Body 'A' (°C)	Initial Temperature of Body 'B' (°C)	Time to Equilibrium (Minutes)	Final Temperature of Body 'A' (°C)	Final Temperature of Body 'B' (°C)	LED Status
1	40.0	30.0	12	34.1	34.0	ON
2	50.0	25.0	18	36.8	36.9	ON
3	60.0	20.0	23	39.9	40.0	ON
4	45.0	35.0	10	39.4	39.5	ON

C. *Analysis and Interpretation*

The apparatus consistently triggered the LED at the moment the temperature difference between the two bodies fell within the threshold range of ±0.2°C. Sensor readings remained stable, and fluctuations were minimal due to the digital precision of the DS18B20 sensors. From the results: The time to equilibrium varied based on the initial temperature gap and thermal insulation of the containers. Final temperatures consistently matched within ±0.1°C, validating the threshold logic. The system responded promptly, with the LED trigger occurring within 10 seconds of reaching equilibrium.

D. *Comparison with Existing Systems*

Most commercial laboratory setups for thermal equilibrium studies involve bulky, analog-based instruments or data loggers, which may lack real-time feedback or automation. In contrast, this Arduino-based system offers:

- Low cost and portability.
- Real-time visual indication using an LED.
- Digital precision with programmable flexibility.

Although commercial systems may provide more comprehensive data logging and advanced thermal control, this project achieves a balance between simplicity, educational value, and functionality—making it ideal for academic labs and learning environments.

IV. CONCLUSIONS

In this project, we were able to design and construct a thermal equilibrium study apparatus employing Arduino technology. The primary aim was to develop a system that is able to sense when two bodies attain thermal equilibrium and to give a distinct visual indication of the moment using an LED trigger. Utilizing temperature sensor DS18B20, the system constantly checks the temperatures of two diverse objects. As the temperature difference between them is within a specified limit—meaning that thermal equilibrium has been established—the LED lights up to indicate the same.

This device provides an effective, affordable means of explaining and illustrating heat transfer and thermal equilibrium principles. The ease of design, paired with the versatility of the Arduino platform, renders it a superior educational device for students and educators alike. It makes it easier to visualize a key principle of thermodynamics in an interactive and hands-on manner, closing the loop between theoretical understanding and actual observation. In addition, the modularity of the system makes future upgrades possible. These enhancements can make the device even more useful in teaching environments, laboratory work, or science fairs. In general, this project not only succeeds in its main goal of detecting thermal equilibrium but also sets the stage for further explorations of heat transfer and sensor-driven automation. It proves how within reach technology such as Arduino can be used in order to build learning experiences in the discipline of science and engineering.

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