

# Dual Adaptive Seat Heater

## 1. Introduction

This project implements a **seat heater control system** for the front two seats (driver and passenger) of a car using the **Tiva C** microcontroller and **FreeRTOS**. Each seat has independent temperature control via a dedicated interface and sensor system. The system also includes diagnostics, user interface output, and CPU usage measurement.

## 2. System Overview

Each seat is equipped with:

- **Heating Level Button(s):** Used to cycle through heating levels (Off, Low, Medium, High).
- **Temperature Sensor:** Monitors current seat temperature.
- **Heating Element:** Controlled based on the desired temperature level.
- **Shared Screen Output:** Displays system status and current seat temperature over UART.

An additional button on the **steering wheel** provides driver seat heater control for improved accessibility.

## 3. Features

### 3.1 Heating Levels

- **Off:** Heater disabled.
- **Low:** Target temperature = 25°C.
- **Medium:** Target temperature = 30°C.
- **High:** Target temperature = 35°C.

The system maintains the temperature within  $\pm 2^{\circ}\text{C}$  of the selected level.

### 3.2 Heater Intensity Control

The heater output intensity is set according to the difference between current and desired temperature:

- $\geq 10^{\circ}\text{C}$  below: **High intensity** (Cyan LED)
- $5\text{--}10^{\circ}\text{C}$  below: **Medium intensity** (Blue LED)
- $2\text{--}5^{\circ}\text{C}$  below: **Low intensity** (Green LED)
- $\leq 2^{\circ}\text{C}$  below: **Heater off**
- Above desired temperature: **Heater remains off** until the temperature drops  $\geq 2^{\circ}\text{C}$  below target

### 3.3 Sensor Diagnostics

- **Valid Range:**  $5^{\circ}\text{C}$  to  $40^{\circ}\text{C}$
- Out-of-range readings indicate sensor failure:
  - Heater is disabled
  - Red LED is activated
  - Failure is logged in memory
  - System resumes operation when valid readings are restored

### 3.4 ADC Integration

- Sensor or potentiometer input is sampled via the **ADC module**.
- Potentiometer range:  $0\text{V}\text{--}3.3\text{V}$  mapped to  $0^{\circ}\text{C}\text{--}45^{\circ}\text{C}$
- Valid operating range for logic:  **$5^{\circ}\text{C}$  to  $40^{\circ}\text{C}$  only**

### 3.5 User Interface

- System status is transmitted over **UART** to be displayed on a car screen.
- Output includes:
  - Current temperature
  - Selected heating level
  - Heater state/intensity

**3.6** Ability to enable and disable heater as the user desires

## **4. Software Architecture**

### **4.1 Real-Time Operating System**

The application uses **FreeRTOS** for multitasking and scheduling:

- **Number of Tasks:** 12
- **Task Reuse:** Logic is reused for both seats with task parameterization

### **4.2 Inter-Task Communication**

- **Queues:** Used for message passing (e.g., temperature data)
- **Semaphores:** Used for event signaling (e.g., button press detection)
- **Mutexes:** Used for exclusive access to shared peripherals (e.g., UART)
- **Event Groups:** For synchronization between tasks (e.g., system status)

### **4.3 Task APIs Used**

- vTaskResume, vTaskSuspend
- vTaskDelay, vTaskDelayUntil
- vTaskPrioritySet, xSemaphoreGive, xSemaphoreTake, etc.

#### 4.4 Interrupts and Responsiveness

- **Edge-triggered interrupts** are used for button handling to maximize responsiveness and reduce CPU load.

#### 5. Microcontroller Abstraction Layer (MCAL)

Custom MCAL modules were developed for:

- **GPIO:** Button and LED control
- **UART:** Output display
- **ADC:** Temperature sensing
- **GPTM:** Timer for delays and CPU usage measurement

#### 6. Diagnostics and Logging

- **Failure events** such as sensor malfunctions are detected, logged in RAM, and notified via UART and LEDs.
- System returns to normal operation when the sensor returns to valid range.

#### 7. CPU Usage Monitoring

- **Manual runtime measurement** using GPTM (General Purpose Timer Module) with 0.1ms resolution.
- Measurements were compared against **FreeRTOS runtime statistics** for validation, but only manual values are used for reporting.

## 8. Runtime tests:

1)

25

Current temperature surpasses desired temperature.  
CPU Load is 6%

30

CPU Load is 6%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 4%  
CPU Load is 4%

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

UPDATE--> Current temperature is: 27.

UPDATE--> Current mode is: Low Intensity Heating.

Desired temperature to be achieved is: 30.

CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 4%  
CPU Load is 4%  
CPU Load is 4%

Driver trying to set temperature lower than seat temperature.

Heater only allows temperature above the seat temperature

2)

25

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

UPDATE--> Current temperature is: 20.

UPDATE--> Current mode is: Low Intensity Heating.

Desired temperature to be achieved is: 25.

Passenger Heater Waiting...

25P

Current temperature surpasses desired temperature.

CPU Load is 11%

Displaying driver seat temperature, which is currently 20, and desired is 25. (temperature difference is  $>2$  and  $\leq 5$ , so mode set is low intensity, with green LED on)

Turning on passenger seat heater, and setting the temperature to 25, which is higher than passenger seat temperature.

3)

CPU Load is 11%

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

Desired temperature to be achieved is: 25.

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

Desired temperature to be achieved is: 25.

CPU Load is 11%

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

Desired temperature to be achieved is: 25.

30

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

UPDATE--> Current mode is: High Intensity Heating.

Desired temperature to be achieved is: 30.

30P

\*\*\*\*\* Displaying Passenger Seat \*\*\*\*\*

Passenger Heater is ON.

UPDATE--> Passenger Current temperature is: 27.

UPDATE--> Passenger Current mode is: Low Intensity Heating.

Desired temperature to be achieved is: 30.

CPU Load is 13%

Displaying passenger and driver seat metrics.

Highlighting that both seats are independent from one another.

4)

30P

```
***** Displaying Passenger Seat *****
Passenger Heater is ON.
UPDATE--> Passenger Current temperature is: 27.
UPDATE--> Passenger Current mode is: Low Intensity Heating.
Desired temperature to be achieved is: 30.
```

```
***** Displaying Passenger Seat *****
Passenger Heater is ON.
Desired temperature to be achieved is: 30.
```

```
***** Displaying Passenger Seat *****
Passenger Heater is ON.
Desired temperature to be achieved is: 30.
CPU Load is 10%
```

```
***** Displaying Passenger Seat *****
Passenger Heater is ON.
Desired temperature to be achieved is: 30.
```

35P

```
***** Displaying Passenger Seat *****
Passenger Heater is ON.
UPDATE--> Passenger Current mode is: Medium Intensity Heating.
Desired temperature to be achieved is: 35.
```

Showing Update from low intensity to medium intensity  
depending on current temperature and desired temperature.



5)

```
Turning Heater ON  
Waiting...  
CPU Load is 14%  
-----ERROR-----  
Driver Seat INVALID TEMPERATURE: Not within range of 5-40  
Turning Heater OFF
```

Showing case of diagnostics task working. This occurs when temperature is invalid. This shows driver seat ONLY facing an issue.

This auto turns off the driver seat heater.

6)

Turning Heater ON

Waiting...

Waiting...

Waiting...

-----ERROR-----

Driver Seat INVALID TEMPERATURE: Not within range of 5-40

Turning Heater OFF

CPU Load is 14%

Turning Heater ON

-----ERROR-----

Driver Seat INVALID TEMPERATURE: Not within range of 5-40

Turning Heater OFF

CPU Load is 14%

Turning Heater ON

Waiting...

25

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

UPDATE--> Current temperature is: 10.

UPDATE--> Current mode is: High Intensity Heating.

Desired temperature to be achieved is: 25.

30

-----ERROR-----

Driver Seat INVALID TEMPERATURE: Not within range of 5-40

Turning Heater OFF

CPU Load is 23%

CPU Load is 11%

CPU Load is 7%

Turning Passenger Heater ON

Passenger Heater Waiting...

25P

Current temperature surpasses desired temperature.

---

Showing that the heater can work if the readings are accurate.

Heater halts when reading is invalid, but works again as soon as readings are within normal range.

Any issue with driver heater doesn't affect passenger heater and vice versa.

7)

```
CPU Load is 0%
Turning Heater ON
CPU Load is 15%
Waiting...

25
CPU Load is 11%

30
CPU Load is 9%
CPU Load is 7%
CPU Load is 6%
Turning Passenger Heater ON
CPU Load is 10%

25P

Current temperature surpasses desired temperature.
CPU Load is 9%
CPU Load is 8%

30P

Current temperature surpasses desired temperature.
CPU Load is 8%
CPU Load is 8%
-----ERROR-----
Passenger Seat INVALID TEMPERATURE: Not within range of 5-40
Turning Passenger Heater OFF

***** Displaying *****
Heater is ON.
UPDATE--> Current temperature is: 24.
UPDATE--> Current mode is: Medium Intensity Heating.
Desired temperature to be achieved is: 30.
Turning Passenger Heater ON
-----ERROR-----
Passenger Seat INVALID TEMPERATURE: Not within range of 5-40
Turning Passenger Heater OFF
CPU Load is 16%
CPU Load is 15%
```

---

Showing that as temperature increases, we notice that increase quickly and don't allow the heater to work if the temperature desired is below the current seat temperature. Then as soon as the temperature surpasses the normal range, the heater forces stop.

We can see here that the passenger has stopped working, but driver was unaffected.

8)

```
35
CPU Load is 14%
CPU Load is 13%
CPU Load is 12%
Turning Heater OFF
CPU Load is 11%
CPU Load is 11%
Turning Heater ON
-----ERROR-----
Driver Seat INVALID TEMPERATURE: Not within range of 5-40
Turning Heater OFF
CPU Load is 13%
CPU Load is 12%
CPU Load is 12%
Turning Heater ON
-----ERROR-----
Driver Seat INVALID TEMPERATURE: Not within range of 5-40
Turning Heater OFF
CPU Load is 13%
CPU Load is 13%
Turning Passenger Heater ON
-----ERROR-----
Passenger Seat INVALID TEMPERATURE: Not within range of 5-40
Turning Passenger Heater OFF
CPU Load is 14%
CPU Load is 14%
```

Showing both seats facing invalid temperature reading error.

9)

25

Current temperature surpasses desired temperature.  
CPU Load is 6%

30

CPU Load is 6%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 4%  
CPU Load is 4%

\*\*\*\*\* Displaying \*\*\*\*\*

Heater is ON.

UPDATE--> Current temperature is: 27.

UPDATE--> Current mode is: Low Intensity Heating.

Desired temperature to be achieved is: 30.

CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 5%  
CPU Load is 4%  
CPU Load is 4%  
CPU Load is 4%

I hardcoded the temperature here to decrease by 2 every 1000ms

The temperature started as 39 degrees (surpassing 25, 30 and 35)  
as shown below



