Temperature controller for a stationary sun baked car

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Introduction
When our car is parked under the sun, it is getting heated by the sun. Like the human body, everything in a car has the property of releasing heat from itself. Since the compartment is a sealed space, there is no place for the heat to escape. This heat will slowly build up and become hotter. Modern cars are equipped with ventilation systems to regulate the air conditions inside the car, such as air quality and interior temperature. However, these systems can only operate normally when the car is on, and they are in standby all other times. Usually, drivers open their car windows to let the heat escape from the car or turn on the air conditioner to cool down the car quickly. Driving a window up and down is the most energy-efficient because temperature is cooled by natural wind. However, the cooling efficiency is much lower than that of air conditioners.

Temperature may not drop to the desired level within 10 minutes by fully opening the windows. It takes a long time to regulate temperature in a large interval, but time can be shortened by reducing the temperature difference in temperature regulation. Our project is using a thermometer to monitor the temperature inside the car in real time and using a controller to control the windows to let the natural wind cool down periodically.

The windows up-down movement is operated by a Direct Current motor. It is controlled by the polarity of current. When the direction of current changes, the movement of the window will be reversed. The rate of temperature drop is depending on the area of the window that is opened, and the rate decreased as the area increased. Our system will open the window in a small percentage of area for safety and energy-saving purposes. Small percentage of opened area will result in a longer interval for temperature regulation and the minimum temperature is higher than that of a fully opened area. The power window will not operate frequently in a short period and therefore it saves the battery consumption.

Method
We use a Negative-Temperature-Coefficient (NTC) thermistor to measure temperature. It has the nonlinear characteristics of higher temperature with lower voltage. The current temperature can be calculated by measuring the output from the thermistor and converted to temperature. When the current temperature reaches a certain level, our windows will be controlled to pull down to a certain temperature level. The system will automatically return to temperature measurement after regulation.

This module outputs an analog signal (voltage) to obtain the temperature.
- a 10k ohms @ 25°C NTC thermistor with $B=3950$
- a 20k reference resistor
- 5V power source

Resistance of thermistor decreases as the temperature increases. We use the series circuit shown in figure 1 to find out the unknown resistance of thermistor.

According to KVL, $V_1 - V_2 = V_{CC} - V_1 = R_{1} \cdot RT$

Based on the change of thermistor resistance, we can calculate the current temperature by

$$RT = R_{25} \cdot e^{\frac{\frac{1}{B}(1 - \frac{T}{T_{25}}))}{T}}$$

$R_{25}$: resistance of thermistor at 25 degree C

B: material constant that is specified on a manufactured thermistor

T: current temperature (T_sensor) in Kelvin

T_sensor (0 to 5V analog) vs. T_sensor (Fahrenheit)

The interval between each degree Fahrenheit is really small that a sampling error of 0.01V will make a misleading on temperature. This error curve is nonlinear, but selecting the value of reference resistor will reduce the error that exists in the desired temperature region.

Our microcontroller (MCU) is going to monitor the temperature and automatically open and close window.
- MCU is sampling current temperatures and the change in temperature.
- When the temperature is saturated that it is not increasing, window should open immediately.
- When the temperature is saturated that it is not decreasing, window should close.
- The window will not open more than half of its area, and each execution should open or close in step of unit digit percentage.
- It is sending the signal to the motor controller and record the window condition as percentage.
- MCU receives interrupt from user. It will stop outputting signal to motor control but still recording temperature.

The power windows up-down movement is controlled by current direction that passes through the DC motor.

Power
Sensor
Motor Control

User Interrupt

Temperature Sensor
MCU

Figure 1, mapping of measured voltage versus the corresponding temperature based on our sensor circuit.

Figure 2, theoretical schematic diagram of a DC motor control

- Only the combination of switch 1 and 4 is controlling forward rotation, and combination of switch 2 and 3 is controlling the reverse rotation.
- When all the switches opened, there is no electrical connection to power the motor which is in the standby condition.
- When V12 is positive, current flow from switch 1 to 4.
- When polarity of V12 is negative, polarity of current flow reverse and therefore motor rotation reverses.

Table 1, combination of switches and their result of motor condition

<table>
<thead>
<tr>
<th>Switch 1</th>
<th>Switch 2</th>
<th>Switch 3</th>
<th>Switch 4</th>
<th>Voltage of motor (V/Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>open</td>
<td>open</td>
<td>open</td>
<td>open</td>
<td>6V</td>
</tr>
<tr>
<td>close</td>
<td>open</td>
<td>open</td>
<td>close</td>
<td>12V</td>
</tr>
<tr>
<td>open</td>
<td>close</td>
<td>close</td>
<td>open</td>
<td>-12V</td>
</tr>
<tr>
<td>close</td>
<td>close</td>
<td>close</td>
<td>close</td>
<td>x</td>
</tr>
</tbody>
</table>

Measurement
We perform a measurement on a stationary car that is parked under the same sunny day in winter by using a thermometer to see the behavior of heating curve and the effect of air exchange on temperature regulation.

Each measurement starts when indoor temperature is approximately equal to the outdoor temperature and ends when temperature is fluctuating or saturated.

Result
We can use an exponential function to fit the heating characteristic from the graphs of fully closed window, 80% closed window, and 60% closed window:

$$dT(t) = dT(1 - e^{-at})$$

The variable a is going to represent the combination of heating and cooling performance because there is more noise involved in the graph when the pull more % of window down, and our equation is meaningless after 40% window opened.

- The exponential curve is the smoothest when window is fully closed because there is no cooling factor to lower the indoor temperature that is 20°F higher than the outdoor.
- At 80% window open, air exchange occurs to bring the heat away from the car and we see the saturation point is dropped about 10°F
- At 60% the curve is still dropping about 5°F from 80%.
- At 40% the graph is full of noise that opening window to regulate temperature becomes a useless method at this point.