Automotive Icing Preventer
ECE 445

By

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Abstract

This paper explores the development of an automotive icing preventer, an innovation aimed at enhancing vehicle safety and operational efficiency in cold climates. The paper outlines the problem of ice formation on vehicles, emphasizing its impact on visibility, driver safety and convenience. It then describes the design of a solution that aims to automate the de-icing process using a combination of heating elements and fans blowing hot air to the windshield, without the need for driver intervention. Detailed are the component selection and system design involved in the design of the device. Furthermore, it discusses potential improvements and future development directions.

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1. Introduction

In regions with severe winter conditions, icing formation on vehicle windshields affects safety, visibility, and overall vehicle functionality. As indicated by the Federal Highway Administration, “nearly 70 percent of the U.S. population resides in snowy areas, underlining a widespread need for effective solutions to combat automotive icing”. Traditional methods of de-icing, such as manual scraping or chemical de-icers, are not only labor-intensive and time-consuming but also potentially harmful to the vehicle's exterior. Additionally, existing automotive heating solutions, like air vents that direct hot air onto the windshield, require the car to be operational, often leading to inconvenient delays, particularly during urgent departures.

Recognizing these challenges, the Automotive Icing Preventer is designed to effectively address and overcome these issues. The design of the Automotive Icing Preventer incorporates advanced heating elements and environmental sensors (temperature sensors) integrated into a smart control system that detects temperature and humidity conditions to activate de-icing as required. Throughout the report, it addresses the details regarding the technical specifications of our system, and emphasizes the reliability and cost-effectiveness of the components used. We will also discuss comprehensive testing procedures that were conducted to validate the performance of the system under various harsh weather conditions.

2. Outline of the Project

2.1 Introduction

The heating system is a boxed machine that features four suction cups mounted to the inside of the windshield of the vehicle. When the heating system is turned on, the warm heat will be transferred through the gap, exerted from slits cut into the box, between the device and the windshield, seen in Figure 2.1. The warm heat spreading all across the windshield will slowly heat the glass up, reducing the ice formed. The PCB, which houses the control unit, amplifiers, and relays, will be located on the inside wall of the box, while the temperature sensor will be installed outside the box and in direct contact with the windshield.

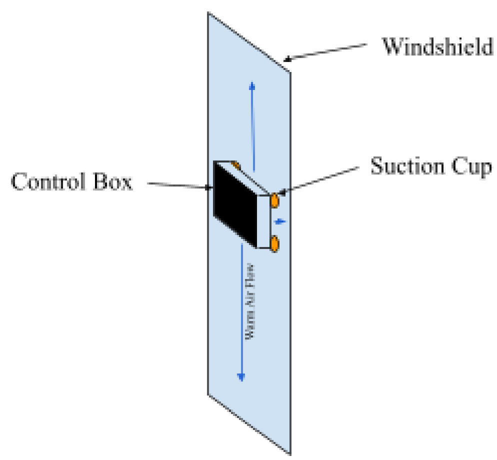

Figure 2.1: Diagram of how box is attached to the windshield

Throughout our design process, we encountered several challenges related to design and component selection, as well as various current and voltage calculations. Consequently, we adjusted our block diagram and refined our physical design to accommodate these changes in component specifications and configurations.

Initially, our design featured one heating element accompanied with one fan. However, considering that the device would need to heat up the whole windshield which is larger in size compared to the initial device design, we increased the number of heating elements and fans to make the device more effective in practice. Figure 2.2 shows the final top level diagram encompassing four heating elements, four fans that would be operating through the relay switches. The diagram clearly presents the power subsystem where we will be supplying power to our device through a 12V power supply, the control unit where the microcontroller would take the temperature sensor input and output to the relays, and the heating subsystem which contains the relays connected to the heating elements and fans.

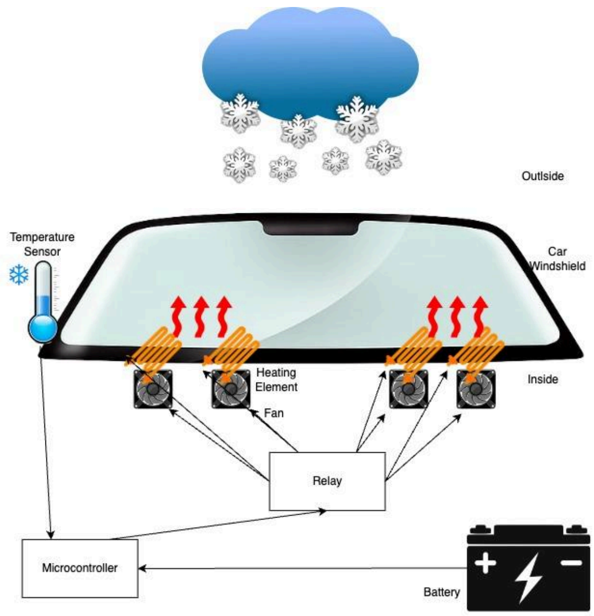

Figure 2.2: Final Top level diagram of device feature

Our three high-level project functionalities were as follows:

1. Temperature Regulation
2. I/O Implementation
3. Power Distribution

For our temperature regulation, we ensured that the heating activates at 0±1°C and maintains surface temperature until it exceeds 10±1°C, ensuring windows stay defrosted for safety and visibility. In addition to validating the functionality of the temperature regulation, the Input/Output implementation is also crucial for the functionality of the device. We solidified that our system, utilizing the ESP32, accurately controls four relays which are connected with an operational amplifier. The relay activates based on inputs from a DHT11 temperature sensor and a manual switch. It powers on if temperatures are below 0±1°C and the switch is 'on'. Lastly, understanding and executing accurate power distribution would significantly impact the overall efficiency of the device. Our system aimed to consume 100W, including power generated from the four fans and heating elements. Also we focused on developing the device to be managed by a 10-minute timer and safeguarded by thorough current analysis to ensure wire and conduit safety.

As seen in Figure 2.3, the boxed shape device would incorporate four heating elements mounted atop a metal stud, with the four fans positioned below. The design includes a lid that easily opens and closes, enhancing the device's accessibility for maintenance and repairs. Ventilation holes are located at the base of the box, beneath the fans, serving as conduits for the warm air to flow seamlessly. Additionally, the heating elements are positioned at a safe distance above the fans to ensure that the plastic components remain unaffected by heat, thus maintaining the integrity and safety of the entire system.

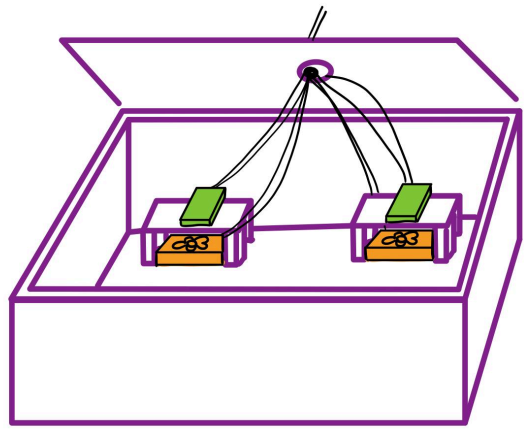

Figure 2.3: Diagram of heating elements and fans in the box

2.2 Design

2.2.1 Design procedure

Our system is composed of four main subsystems that we agreed upon to be necessary for full operation of the device. The power subsystem, consisting of a 12V and 5V battery source, are necessary for supplying voltage to the heating and sensor subsystems, as well as the controller subsystem, respectively. The controller subsystem is our microcontroller, responsible for sending out conditional voltages to the relays through the operational amplifier when prompted by the sensor subsystem. The sensor subsystem is necessary for sending digital temperature data to the microcontroller for interpretation. Lastly, the heating subsystem, consisting of four fans and four heating elements, receives power from the relays to heat the windshield.

Regarding alternative design approaches, there are three main areas of interest to consider: the sensor subsystem, the relays, and our operational amplifier. Our initial idea for the sensor was to implement a Type K thermocouple with a voltage amplifier to send an analog input into the microcontroller. This would have been widely inconvenient and required the usage of a multimeter to test the output voltage at various temperatures to set conditions within the microcontroller. Instead, we opted for the DHT11 sensor after considering the ADT7420 due to its wiring simplicity, as well as ability to read humidity on top of temperature, a feature the ADT7420 does not possess. Another design consideration is in regards to the relays. After our final circuit implementation was procured utilizing the relay modules, we learned that an NPN bipolar junction transistor in a common emitter configuration could also be utilized. This would not only save a marginal amount of time, but would also be a more cost efficient option, using significantly less transistors than what consists within a relay, with a minimal sacrifice of voltage. Lastly, similar to the consideration behind the relays, rather than using an operational amplifier, a BJT could similarly be used to step up the voltage required for the relays rather than an operational amplifier, which we also learned after building our final implementation.

Figure (2.4) below shows the general outline of our final circuit.

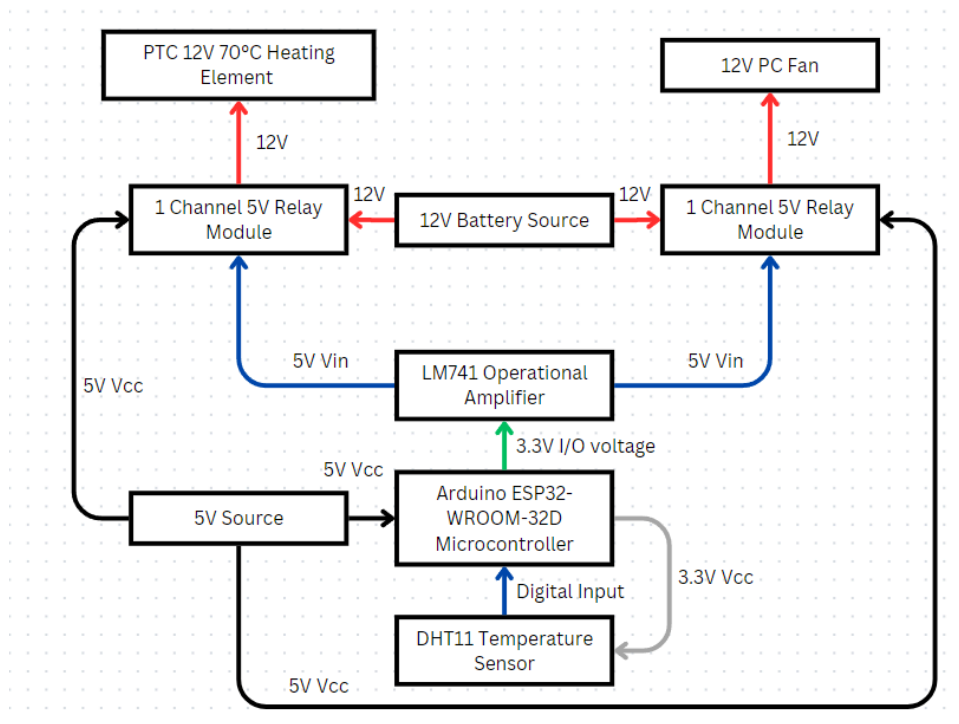

Figure 2.4: Block diagram of device system

Our calculations primarily went into the operational amplifier for ensuring a step up output of the microcontroller's digital pin voltage output from 3.3V to 5V to prompt the relays to supply voltage. Equation (2.1) shows the non-inverting operational amplifier gain equation used.

$$G = \frac{Vout}{Vin} = 1 + \frac{R2}{R1} \qquad \text{(Equation 2.1)}$$

2.2.2 Design details

Ensuring a safe circuit analysis and executing accurate output values is essential when designing a device. Throughout our design process we have considered different values of components to essentially generate the output we expected.

Starting off with our power subsystem, we supplied a 12V power supply to the whole system which was used throughout the circuit, especially to power the load of the four fans and heating elements through the relay pinout shown in figure (2.5) using the normally open configuration. The 12V power supply was utilized for the operational amplifier to gain its voltage increase, along with V_{cc} inputs to the temperature sensor. A 5V power supply was then used for the microcontroller and relay V_{DD} inputs.

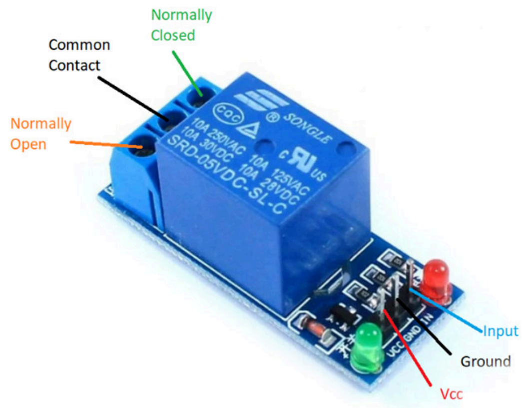

Figure 2.5: Arduino Relay Module Pinout[7]

Within the controller subsystem, we utilized a voltage supply from the computer, connected through the UART. The part we needed to keep in consideration was that the ESP32 would only output a voltage of 3.3V as referred to in table (2.1), which is significantly lower than the voltage required to switch the relays for the heating subsystem.

Symbol	Parameter	Min	Typ	Max	Unit
C_{IN}	Pin capacitance	-	2	-	pF
V_{IH}	High-level input voltage	0.75×VDD[1]	-	VDD[1]+0.3	V
V_{IL}	Low-level input voltage	–0.3	-	0.25×VDD[1]	V
I_{IH}	High-level input current	-	-	50	nA
I_{IL}	Low-level input current	-	-	50	nA
V_{OH}	High-level output voltage	0.8×VDD[1]	-	-	V
V_{OL}	Low-level output voltage	-	-	0.1×VDD[1]	V

Table 2.1: ESP32 DC Characteristics (3.3V, 25°C)[3]

To procure a 5V input as required by our relay modules, we utilized an LM741 operational amplifier. Using a non-inverting configuration and utilizing equation (2.1), we were able to calculate the values of R_1 and R_2.

$$G = \frac{Vout}{Vin} = \frac{5}{3.3} = 1 + \frac{R2}{R1}$$

$$R_2 = 220\Omega$$

$$R_1 = 470\Omega$$

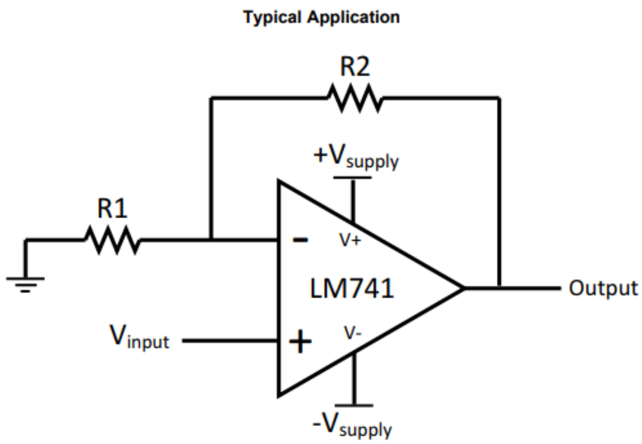

Figure 2.6: Typical Application of LM741[5]

Figure (2.7) provides the necessary pinout for the DHT11 temperature sensor, aka our temperature subsystem. This very simple implementation plays possibly the biggest role in the device: overall temperature and humidity detection. The DHT11 is connected to the 12V supply, with the digital data pin connected directly to the microcontroller to provide the necessary readings for the device to operate.

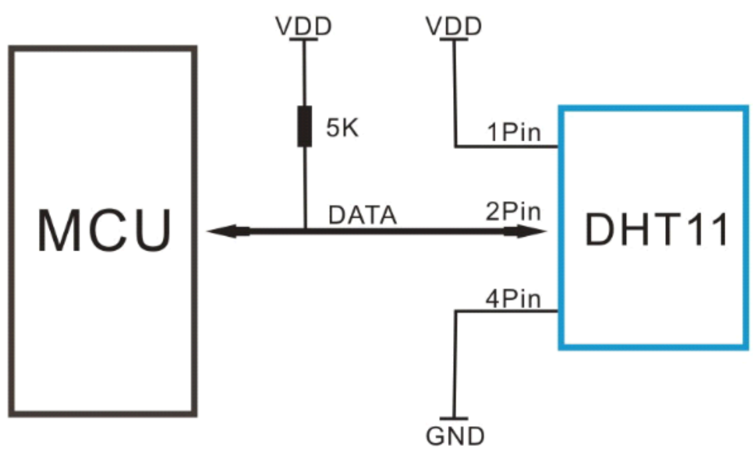

Figure 2.7: Typical Application of DHT11[6]

Lastly we have our heating subsystem. The heating subsystem consists of four 12V, 50W PC fans and four 12V, 50W PTC heating elements. When prompted by the sensor and microcontroller subsystems, this unit receives 12V to supply heated air to the windshield.

2.3 Verification

Testing the automotive icing preventer is critical to ensure it meets its design goals of efficiency, safety, and functionality. To test the completed project, we created a list of requirements and verifications that would illustrate the functionality of the completed project as a whole and its major blocks, including all the subsystems. Table (2.2) shows the final list of requirements and verifications.

Requirement	**Verification**
5V output from Op Amp.	Microcontroller output 3.3V, LM741 chip output 5V
System can switch off despite the temperature threshold.	Switch == OPEN -> no voltage Switch == CLOSED -> 12V to heating elements and fans
PTC elements reach rated 70°C.	Thermometer
Fans receive 12V.	Prompt sensor/microcontroller 12V output
ESP 32 is programmed to interpret DHT11 data.	Temperature read -> digital I/O conditions

Table 2.2: Table of Requirement and Verification for completed project

In order to test the LM741 Operational Amplifier (Op Amp) that is connected to the microcontroller and the relays, we had to test the voltage input and output. A multimeter was used to measure the input and output voltages, which were measured to be 3.3V and 5V.

The device should have an on/off switch, which the user could use to turn the heating subsystem on and off without relying on the temperature sensor's output . Just like the user would, we could test the switch by looking at the device turning on and off according to the switch state. To be more specific, we measured the voltage going to the heating subsystem, specifically the fans and the heating elements, when the device was on and off. When the switch was off, there was no voltage. When the switch was turned on, we could see that the fans started turning, and there was 12V going to the fans. Through this process, we could also test that the fans were correctly operating. However, this verification also showed that there was no voltage going to the heating element, which did not heat up, indicating that the heating elements were not working. Consequently, we could not use a thermometer to measure the temperature of the heating element. We suspected that this malfunctioning could have resulted in a faulty relay that powered the heating elements or a hidden error in the overall circuit analysis.

To test the ESP32 interpreting temperature data from DHT11, we utilized the serial print in Arduino IDE, which printed the temperature read from the DHT11 signal that was inputted to the microcontroller. Additionally, we could adjust the temperature condition statements in the program code so that the microcontroller would output 3.3V according to the temperature. In our case, we would want the microcontroller to output voltage when the temperature is below 1℃ and stop the voltage output when the temperature goes above 10℃. Figure (2.8) below shows the implementation to complete this requirement.

```
void loop() {
// Check the switch state
systemActive = digitalRead(switchPin); // Read the switch status
float temperature = dht.readTemperature();
Serial.println("Temperature:");
Serial.println(temperature);
Serial.println("\n");

if ((systemActive) && temperature < 1) {
  digitalWrite(relayPin, LOW); // Turn on the relay
  Serial.println("Heating system turned on.");
}
else if ((systemActive) && temperature >= 10) {
  digitalWrite(relayPin, HIGH); // Turn off the relay
  Serial.println("Heating system turned off.");
}
else {
  digitalWrite(relayPin, HIGH); // Turn off the relay if the switch is not active
  Serial.println("Heating system turned off.");
}

delay(1000); // Simple delay to prevent constant looping
}
```

Figure 2.8: DHT11 I/O in Arduino IDE

2.4 Costs

The total cost for parts as seen below in Table (2.3) before shipping is $ 62.53. Our development took 80 hours of completion time, we can expect a salary of $40/hr x 2.5 x 60 hr = $6000 per team member. The total cost comes out to $62.53 + ($6000 x 3 team members) = $18,062.53 plus shipping and handling.

Description	Manufacturer	Quantity	Price
DHT 11 - Temperature Humidity Sensor 16bi[6]	UNIVERSAL-SOLDER Electronics Ltd	1	$ 1.99

5 VDC Household Appliance 5 Pin PCB Relay SRD-05VDC-SL-C[7]	Ningbo Songle Relay Co.,ltd	4	$ 3.56
DC 12V Mini Cooling Fan 2Pin Brushless Small Exhaust Fan	ZYAMY	4	$ 15.98
PTC HEATING ELEMENT PLATE	PTCYIDU	4	$ 23.98
SWITCH TACTILE SPST-NO 0.05A 12V	C&K	1	$ 0.17
LM 741 Operational Amplifier[5]	Texas Instruments	2	$ 0.87
ESP32 DEVKIT ESP32-WROOM-32[3]	Espressif	1	$ 15.98

Table 2.3: Parts Cost Analysis List

2.5 Design Schedule

Week	Task	Person
2/19	Order parts for prototyping	Everyone
2/26	PCB Schematic Draft PCB Design PCB Components	Everyone Jiwon Joon and Taseen
3/4	Finish PCB Schematic and meet with ECEB Parts shop to finalize mechanical design	Everyone
3/18	Receive Parts Start subsystems components testing Update PCB design	Everyone Taseen Jiwon
3/25	Start with wiring one relay connected with a fan and heating element, verifying/testing if the components were receiving the required supply voltages Update PCB design	Everyone Jiwon
4/1	Check power and sensor subsystems work as intended and increase the number of relays wired on to the bread board Write a simple code to check/verify the functionality of the temperature sensor and the outputs. Troubleshoot programming errors and updated circuit analysis for breadboard testing.	Everyone Joon Taseen
4/8	Integrate entire project systems including the heating subsystem, sensor subsystem, control subsystem, and power subsystem. Verify each component is operating as expected.	Everyone

4/15	Mock Demo, Test and Debugging	Everyone
4/22	Final Demo / Paper	Everyone
4/29	Final Presentation/Paper	Everyone

Table 2.4: Design schedule

3. Conclusions

The scope of this project required physical and electrical implementations to bring together a final product. We produced a device that is capable of mounting to the windshield and supplying air based on temperature. Our project achieved significant milestones, successfully implementing a sensor and control system that efficiently detects temperature changes and activates de-icing processes. The integration of an ESP32 microcontroller facilitated sophisticated control mechanisms, and the system's power subsystem effectively harnessed 12V to power all components, ensuring reliable operation and potential future enhancements. Despite these successes, there are still three main uncertainties to be resolved. First, we need a physical design that spans a wider region of the windshield without obstructing the driver's view. An ideal alternative is a device that spans the bottom of the windshield, delivering heated air upwards so as to not obstruct the driver's view and not be a nuisance. Second, the issue behind the heating elements needs to be resolved. While all other components of the system operate as expected, the heating elements did not receive voltage. A potential alternative solution here would be to introduce a second operational amplifier or a bipolar junction transistor to separately supply voltage to the heating elements rather than being outputted from the same source as the fans. Finally, a further current analysis is required for the heating subsystem. Wire conduits play a primary role in the amount of current that may pass through, and while our fans did receive the necessary power output, we would like to see a more optimized heating subsystem, whether it be outputting more power through less heating elements, or outputting more power to the number of heating elements we currently have. An alternative design or use for our product can be automatic air conditioning, which detects the hot temperature, and automatically turns on the fans to cool down the surrounding environment, taking out the heating elements and making the product more cost-effective as well.

This is all in conjunction with IEEE Code of Ethics I.1: to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to promptly disclose factors that might endanger the public or the environment. We strived to create a product that promotes safety and sustainability for the public. With a little bit of more optimization of our internal systems and physical design, this can fully be achieved.

4. References

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