ECE 445 Project Proposal

Adriel Taparra
Kahmil Hamzat
James Raue

1 Introduction

1.1 Problem

Bridges pose a significant safety hazard in the winter due to their increased susceptibility to ice compared to standard roadways. Unlike roads, which retain some heat from the ground, bridges are exposed to cold air from all sides, accelerating the freezing process. This causes hazardous driving conditions which can potentially lead to accidents, road closures, and traffic. Currently, the solutions are to put on passive warning signs such as "Bridge Ices Before Road". While the signs inform the driver, it does nothing to prevent ice accumulation. According to the U.S. Department of Transportation, Federal Highway Administration 21% of all vehicle crashes are weather-related. Implementing an automated heating system to prevent ice formation on bridges can significantly enhance road safety by reducing the likelihood of ice-related incidents.

1.2 Solution

Our proposed solution is a heated bridge safety system that actively prevents ice buildup by using an array of heat cartridges embedded beneath the bridge's surface. The system will be controlled by a microcontroller that continuously monitors real-time weather conditions through temperature, moisture, and precipitation sensors. When freezing temperatures and moisture are detected, the system will activate the heating elements, ensuring that ice does not form.

To demonstrate this concept, we will construct a simulated bridge model with a metal sheet to represent the road surface, under which heating cartridges will generate heat. A MOSFET-based power switching circuit will efficiently regulate power delivery to the heating elements. The power supply will be sourced from a 12V or 24V DC adapter, with the potential for a rechargeable battery and DC-DC converter integration. By activating only when necessary, the system will minimize energy consumption while maintaining a safe, ice-free surface. The effectiveness of this prototype will be tested in a controlled environment to evaluate its heating capability and responsiveness to changing conditions.

1.3 Visual Aid

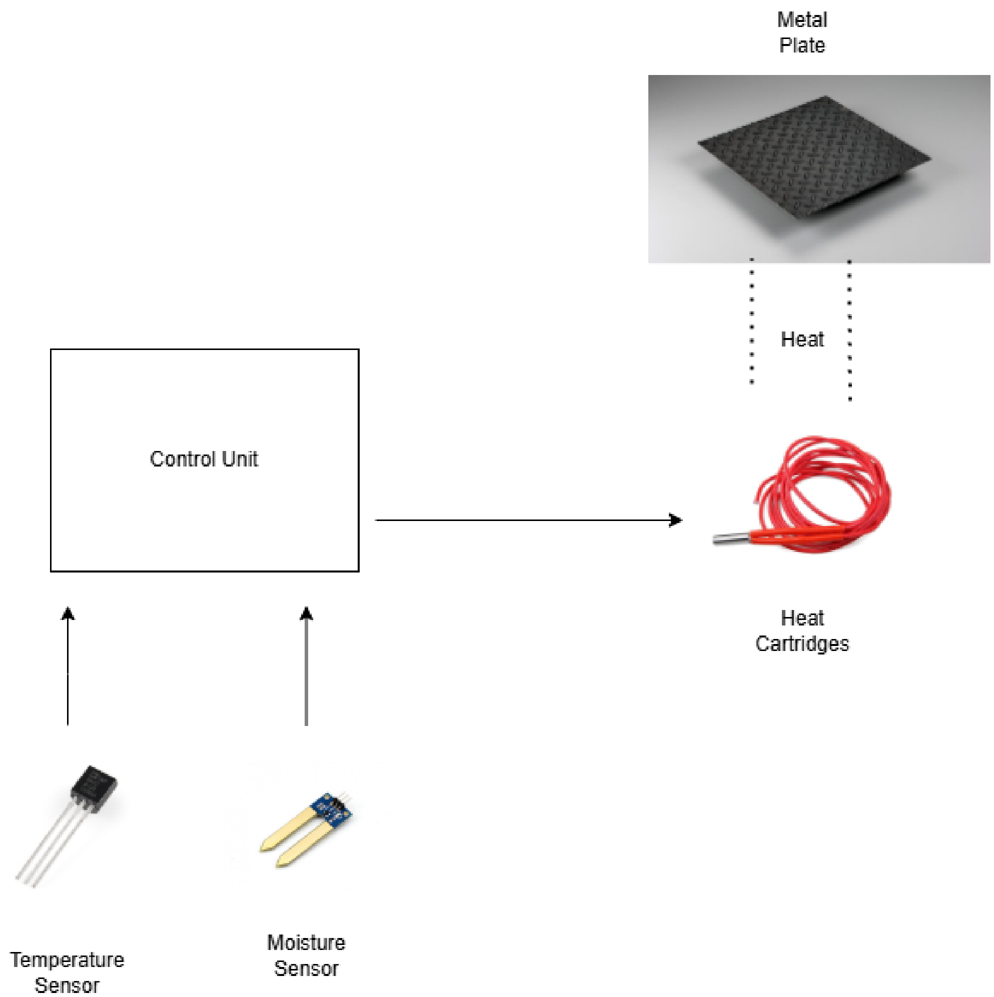

Figure 1: Block Diagram

1.4 High-level requirements list

- **Accurate environmental sensing** – The system must reliably detect surface temperature, moisture presence, and precipitation with an accuracy of at least ±1°C for temperature and a clear binary (wet/dry) output for moisture detection to ensure proper activation of the heating system.
- **Efficient heating capability** – The heating elements must generate enough heat to raise the bridge surface temperature above freezing (0°C) within five minutes of activation in simulated icy conditions.
- **Automated power regulation** – The heating system must activate only when freezing temperatures and moisture are detected and automatically deactivate once conditions are no longer hazardous, optimizing power usage and preventing unnecessary energy consumption.

2 Design

2.1 Block Diagram

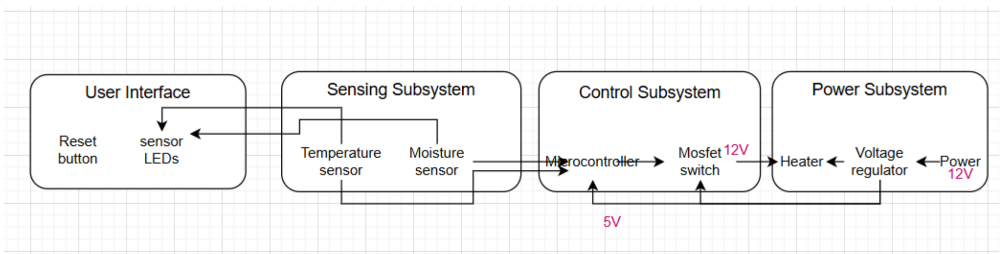

Figure 2: Block Diagram

2.2 Subsystem Overview/Requirements

2.2.1 Power Subsystem

The power subsystem is in charge of supplying power to all our components. It ensures that all components get the necessary power they need to function without getting shorted or blowing a fuse. This subsystem has connections to the control and sensing subsystem to ensure that we are able to sense weather conditions accurately and turn on the heater as needed.

The Power subsystem must be able to supply 5V ± 0.1V to the ESP32 microcontroller by using a converter to step down the 12V voltage from the wall outlet. This subsystem is also in charge of supplying power to the heating element (nichrome wires/heater cartridge). It must supply 12V ± 0.5V directly to the heating element using a MOSFET switch to determine when power should be supplied. It must also supply at least 5A continuous current to the heating element when required.

2.2.2 Sensor Subsystem

The sensor subsystem comprises two sensors. The temperature sensor and the moisture sensor. The temperature sensor will help us detect freezing conditions while the moisture sensor will detect rain or snow. The outputs of these sensors will be interfaced with the ESP32 to determine the appropriate time to turn on/off the heater.

The temperature sensor should have an accuracy of ±2F and be able to detect temperatures below the freezing point (32F). The moisture sensor must also be able to detect when a sizable amount of liquid falls on it so we can trigger the heater as needed.

2.2.3 Control Subsystem

The control subsystem determines when to activate the heater based on the weather conditions sensed by the sensors. The control subsystem will also interface with LEDs and a reset switch to relay appropriate information about the status of the sensors and allow us to reset the system and turn it on/off.

For this subsystem to function properly, the ESP32 must read sensor values at least once every second. The control subsystem should send an "on" signal to the MOSFET (thereby turning on the heater) if two conditions are met. First, when the temperature is at or below the freezing point (32F) and second when moisture (rain or snow) is detected. For the ESP32 to send an "off" signal, at least one of two conditions must be met. Either the measured temperature is greater than 34F (we have a buffer range to prevent rapid cycling) or there's no moisture detected. In these cases, the ice/snow will either melt due to the natural heat from the sun or there's no condition for ice formation in the first place (no moisture).

2.3 Tolerance Analysis

For our project to be successful, we need to make sure the heating element produces enough heat to prevent ice formation while also being energy efficient. A potential risk is that the heating element may not reach the required temperature to melt the ice or we might not be able to produce enough power for heating. If we were to use 2 heater cartridges each rated at 30W and 12V then we would need to supply at least 5A (60W/12V) at 12V to make sure the heaters don't underperform.

We also need to consider how long it will take to raise the surface temperature by a certain amount to make sure that the amount of power we supply can raise the bridge temperature in a reasonable amount of time. If we use a 2kg aluminum sheet with a heat capacity of 900 J/(kg·°C) and we want to raise the temperature by 5 degrees then we would need $Q = mc\Delta T = 9000J$ of heat and this would take 150 seconds (9000J/60W). If we use 3 cartridges then we would be down to 100 seconds. Using these calculations, we can determine how many cartridges we need to melt the ice in a reasonable amount of time.

3 Ethics and Safety

3.1 Dangerous Conduct

Due to the nature of our project relating to the use of large amounts of energy and heat, it is especially important that we avoid dangerous conduct, as described in the student code 1-302-a. If we are reckless during the design and testing process of our project, we could start a fire which could cause bodily harm or property damage. Because of this, we must take all necessary safety measures when designing, building, and testing our project.

3.2 Public Safety

As this project is intended for public use, it is our responsibility to ensure the highest level of safety in its design, and keep in accordance with the IEEE Code of Ethics, Section I.a. There are many different aspects involved in maintaining this. This includes ensuring that our electronics are safe for public use by adding fail-safe mechanisms, testing under various conditions, and keeping any potentially dangerous electrical equipment inaccessible to the public. We also need to consider all of the public safety concerns involved in making a normal bridge. This includes ensuring structural integrity, pedestrian safety, and durability over time. We can ensure that we maintain accordance with this by making sure that we follow all relevant codes and laws surrounding bridge construction. This can be done by following guidelines such as the AASHTO LRFD bridge design specifications manual.

3.3 Work Only in Areas of Competence

The ACM Code of Ethics section 2.6, mandates that engineers perform work only in their areas of competence. In order to keep in accordance with this, we must acknowledge that our area of competence relates to electrical and computer engineering, and that that knowledge alone is insufficient to design a bridge. Our team will ensure that for areas of knowledge beyond our expertise, such as structural engineering, materials engineering, and advanced thermodynamics, we consult qualified personnel.