**Project Proposal: Weather-Resilient Camera System for Autonomous Vehicles**

Team #50

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# Introduction:

### Problem:

Snow and freezing temperatures can severely impair the functionality of car cameras used for object detection, particularly in autonomous and driver-assist systems like those in Teslas. When snow, ice, or frost accumulates on these cameras, their ability to detect objects, pedestrians, and other vehicles is significantly reduced, potentially leading to critical safety hazards. This issue is especially concerning in regions with harsh winters, where camera obstructions can compromise autonomous vehicle performance and driver assistance features.

Despite the growing need for reliable vision systems, current solutions remain inadequate in effectively addressing this issue. Many approaches attempt to either enhance camera hardware or refine object detection algorithms, but they often fail to work together in a comprehensive manner. For instance, snow and ice can obstruct sensors, causing issues like false proximity warnings from blocked ultrasonic sensors, and cameras face reduced visibility from falling precipitation and increased glare from snow-covered fields.
(https://areaxo.com/blog/let-it-snow-winter-testing-for-cars-robots-and-drones/?utm_source=chatgpt.com)

The U.S. Department of Transportation has also reported that ice or snow on radar and camera sensors can disable all vehicle safety systems, further highlighting the severity of this problem.
(U.S. Department of Transportation)

Addressing this challenge is crucial for ensuring the safety and reliability of autonomous and driver-assist systems in adverse weather conditions.

## Solution:

Our system ensures car cameras remain functional in adverse weather by integrating real-time detection and response mechanisms. By continuously monitoring environmental conditions, the system proactively prevents obstructions from impairing visibility. Temperature and moisture sensors detect when freezing or condensation is likely, while an optical detection system analyzes the camera's view for obstructions. This allows the system to respond dynamically, ensuring clear vision for autonomous and driver-assist systems in all weather conditions.

When snow or ice accumulation is detected, a targeted heating element activates to clear the lens, preventing buildup that could compromise object detection. For rain, an optical detection system identifies raindrops in real-time using a pretrained convolutional neural network (CNN) deployed with TinyML. The CNN, optimized for low-power environments, operates efficiently with an estimated 5-7MB of memory, enabling real-time raindrop detection on embedded hardware. Upon detecting rain, the system applies a hydrophobic nanocoating to the lens, repelling water droplets. In heavy rainfall, the heating element further ensures visibility by evaporating moisture. A microcontroller coordinates these responses, processing sensor data and triggering the appropriate actions. A rechargeable Li-ion battery with voltage regulation powers the system, maintaining stable performance. By combining these technologies, our solution provides a comprehensive approach to maintaining camera functionality, improving the reliability and safety of object detection systems in autonomous and driver-assist vehicles.

Our system provides significant benefits to consumers by enhancing the reliability and safety of autonomous and driver-assist vehicle systems in adverse weather. By ensuring uninterrupted camera functionality, it reduces the likelihood of sensor failures that could lead to accidents, giving drivers and passengers greater confidence in their vehicle's safety features. Additionally, this automated solution minimizes the need for manual intervention, such as wiping off cameras or waiting for defrosting, improving convenience for users, especially in extreme weather conditions. The system's energy-efficient design, powered by a rechargeable Li-ion battery, ensures it operates seamlessly without draining the vehicle's main power supply, making it both practical and cost-effective.

Several key features make this solution highly marketable. The integration of real-time detection and response mechanisms provides a proactive, self-maintaining system that outperforms existing passive solutions like simple hydrophobic coatings or basic heating elements. The use of TinyML allows for efficient, low-power operation, making it viable for widespread adoption in both consumer and commercial vehicles. Additionally, the combination of advanced machine learning and targeted physical interventions—such as hydrophobic nanocoatings and heating elements—sets this system apart from competitors. By addressing a well-documented problem in the automotive industry, this solution presents a strong value proposition for manufacturers seeking to improve the reliability of their autonomous and driver-assist technologies.

**Visual Aid:**

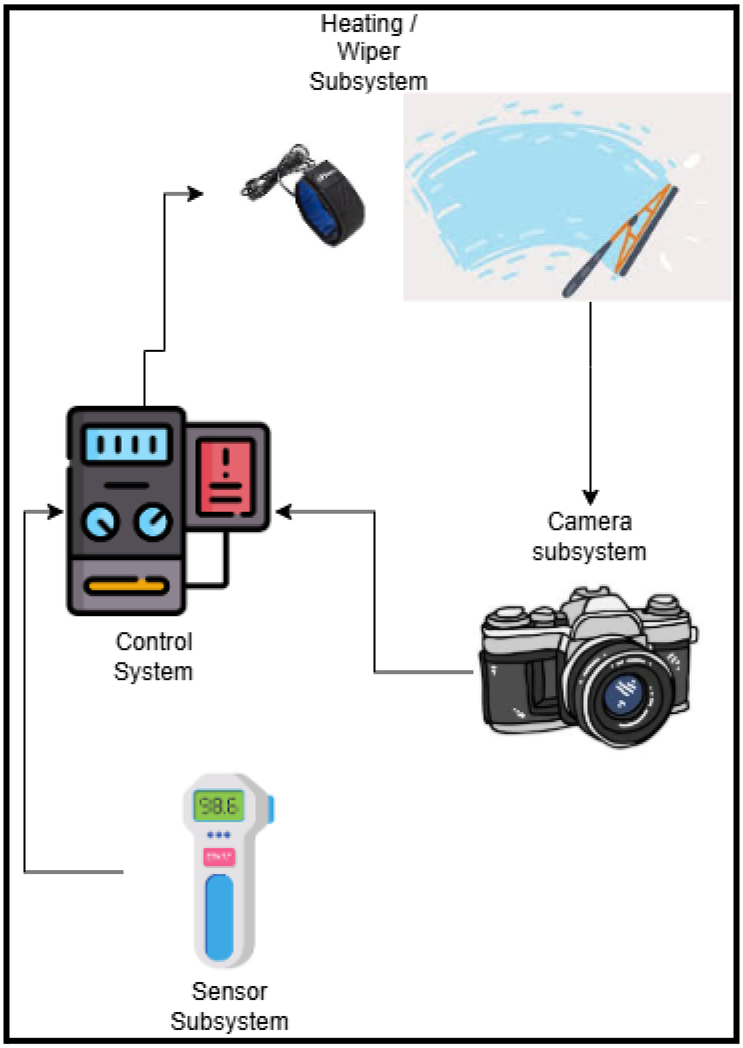


*Figure 1*

## High Level Requirements List:

- The system must detect raindrops and ice obstructions with at least 75% accuracy using the TinyML-based computer vision model and sensor inputs under simulated rainy and snowy conditions.
- The wiping mechanism must activate within 2 seconds of raindrop detection, and the heating element must begin melting ice within 5 seconds, fully clearing obstructions within 30 seconds.
- The system must operate continuously for at least 2 hours on a fully charged Li-ion battery, ensuring stable performance across all components without significant degradation in functionality, which is crucial for long-duration drives.

# Design:

## Block Diagram:

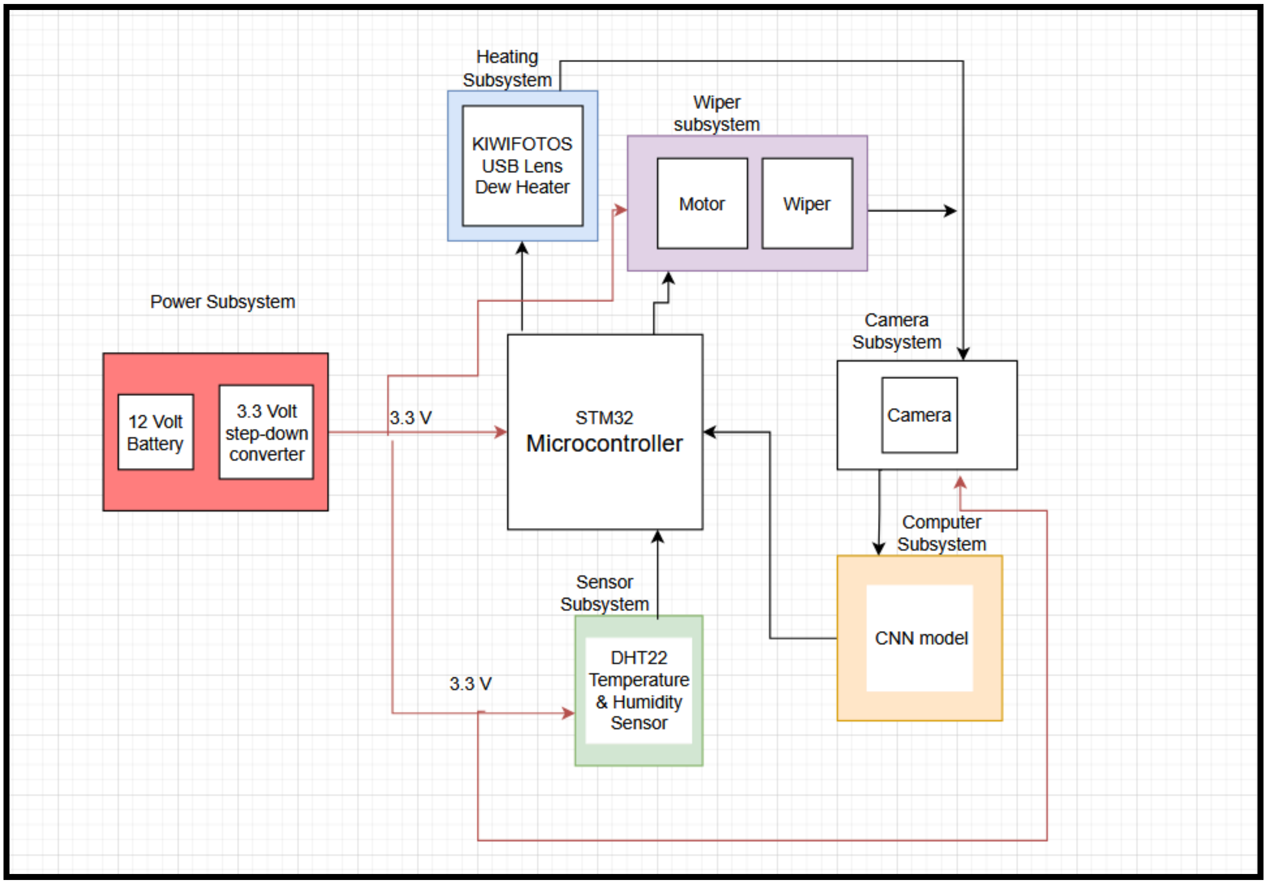


*Figure 2*

## Subsystem Overview:

### *Camera Subsystem:*

There are two aspects of the camera subsystems, the physical camera itself and the camera feed it generates. The purpose of the project is to keep the camera dry and clear. As such the requirements are: the camera must be kept at a around 21°C temperature, the lens must be clear when it is raining, and the camera feed must be used to detect the rain.

### *Heating Subsystem:*

There is one major aspect of this subsystem which is the Lens heater which will be placed on the camera. As mentioned above the goal of this project is to keep the camera dry and clear. When there is ice formation detected over the camera, the heating subsystem will be activated to heat the lens enough to thaw the ice allowing the wiper to clear it off the camera.

### *Sensor Subsystem:*

The Sensor Subsystem will be used to determine whether or not there is ice formation on the camera lens. It will interface with the microcontroller and depending on the results from the OpenCV, it will activate the heating subsystem.

### *Power Subsystem:*

The Power Subsystem will deliver power to each subsystem that requires it. There will be a 12 volt battery with a 3.3 volt step-down converter to ensure the proper operation of each subsystem.

### *OpenCV Module Subsystem:*

This subsystem is responsible for detecting rain/ice obstruction over the camera. This will detect precipitation and will inform the microcontroller when to apply the wiper/heating subsystems. It will interface directly with the camera subsystem as it requires the camera feed to detect precipitation

### *Microcontroller Subsystem:*

This will connect all of the different subsystems to work together to implement our solution for a weather resilient camera.

## **Subsystem Requirements:**

### *Camera Subsystem:*

- The camera must be kept at a around 1-30°C temperature, the lens must be clear
- When it is raining, the camera feed must be used to detect the rain through the CNN model.
- It will interface as a input to the OpenCV subsystem as that subsystem requires camera feed as input

### *Heating Subsystem:*

- The heating system must interface with the STM32 Microcontroller to receive on/off signals
- The heating system must turn on when the temperature reaches 0°C and if there is blockage detected.
- The heating system must turn off after 30 seconds of heating.

### *Sensor Subsystem:*

- The heating system must interface with the STM32 Microcontroller to send temperature values 5 seconds

### *Power Subsystem:*

- The voltage must start at 12+/-.5 V
- The 12 to 3.3 voltage step-down converter must deliver 3.3+/- .1V

### *OpenCV Module Subsystem:*

- Will Run a pretrained CNN based on an AlexNet model aiming for about 75% accuracy in detecting raindrops
- It will interface with the camera subsystem as it requires the cameras feed to detect precipitation
- Will interface directly with the STM32 microcontroller and will be return a boolean value for if enough precipitation is detected (True/False)

### *Microcontroller Subsystem:*

- Will be an STM32 Microcontroller that is used to connect all the various other subsystems
- Will receive temperature values from the Sensor Subsystem and precipitation data from the OpenCV subsystem
- If it is 0 degrees Celsius or below and there is precipitation it will activate the heating element for 30 seconds before wiping off the lens with the motor connected wiper
- If the temperature temperature is above 0 degrees celsius and there is precipitation detected the motor connected wiping system will be activated

### Tolerance Analysis:

One potential risk to the successful completion of our project is the interference caused by the wiper mechanism when it runs, potentially blocking the camera's view for a brief period. This could result in inaccurate raindrop detection, as the CNN may process a blocked or partially obstructed image. To mitigate this issue, we need to account for the time the wiper covers the camera lens and pause the CNN during this period to avoid interference with raindrop detection.

We can model the time the wiper covers the camera lens based on its radius and speed, using rotations per second for the wiper speed. We are estimating that we will configure the wiper so it makes 2 quarter rotations in order to wipe the camera lens. We are estimating the wiper Speed ($\omega$) to be 2 rotations per second (the number of full rotations the wiper motor makes per second). $\omega = 2$.

Now, we calculate the time it takes while the wiper covers the camera lens:
time = $\frac{1}{4} \cdot (1 / \omega) \cdot 2 = 0.25$ seconds.

Thus, the wiper will take approximately 0.25 seconds to completely cover the camera lens. During this time, we will pause the CNN model to avoid processing blocked or incorrect images. After 0.25 seconds, the wiper will have cleared the lens, and the CNN will resume processing to detect raindrops or ice.

# Ethics and Safety:

### Ethics:

The development of our weather-resilient camera system for autonomous vehicles involves several ethical considerations. We adhere to the IEEE Code of Ethics, which stresses the importance of "accepting responsibility in making decisions consistent with the safety, health, and welfare of the public." Our project aims to enhance the safety and reliability of autonomous vehicle systems by ensuring clear camera visibility under adverse weather conditions, potentially preventing accidents caused by impaired object detection.

However, ethical concerns arise regarding data privacy and security. The camera system may collect visual data, which could be sensitive if misused. We must ensure that the data captured is securely stored and processed, adhering to ACM Code of Ethics: Principle 1.6 and other similar regulations, depending on where the technology is deployed. In line with IEEE Principle #1, we will maintain transparency and integrity in the development and deployment of this technology.

We also recognize the importance of sustainability in our project. The materials used, including the hydrophobic coating, must not be harmful to the environment. In line with IEEE Code of Ethics Principle 7, we will follow ethical guidelines for sourcing materials and developing products with minimal environmental impact. Additionally, our system's power consumption will be optimized to reduce its carbon footprint.

## Safety:

Safety is a paramount concern for both the development of the system and its future deployment in autonomous vehicles. Several safety guidelines apply to our project:

Electrical Safety: The project involves using a microcontroller (STM32F746NGH6) and a rechargeable Li-ion battery. These components pose electrical risks, including short circuits, overvoltage, and thermal runaway in batteries. We will follow safety protocols for handling Li-ion batteries and use voltage regulation circuits to ensure stable power distribution. The Li-ion battery pack will be properly insulated, and we will implement overcurrent and overvoltage protection.

Mechanical Safety: The system will include a heating element and a wiper mechanism. Proper safety measures will be taken to avoid electrical or mechanical failure that could cause harm. The heating component (KIWIFOTOS USB Lens Dew Heater) will be securely mounted and operate within safe temperature limits to prevent burns or fire hazards. The wiper mechanism will be carefully constructed to avoid damage to the camera or other components.

Lab Safety: In the development phase, lab safety protocols will be followed, particularly with regard to handling electrical components and chemicals like the spray-on cleaning solutions. We will ensure the proper storage and handling of hazardous materials and work in a well-ventilated environment when applying the hydrophobic coating and cleaning solutions. Safety goggles and gloves will be worn when working with these substances to avoid contact with the eyes or skin.

End User Safety: From an end-user perspective, the system is designed to improve safety by ensuring that cameras in autonomous vehicles remain functional under various weather conditions. However, misuse could arise if the system is tampered with, or if the maintenance of the system is neglected. Clear instructions will be provided for installation, maintenance, and troubleshooting to minimize risk.

# References:


[1] A. B. Author, “Let it snow: Winter testing for cars, robots, and drones,” Areaxo, [Online]. Available:https://areaxo.com/blog/let-it-snow-winter-testing-for-cars-robots-and-drones/?utm_source=chatgpt.com. [Accessed: Feb. 12, 2025].

[2] Automated Vehicles and Adverse Weather Final Report, Battelle, U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology, Federal Highway Administration, FHWA-JPO-19-755, June 2019. [Online]. Available: www.its.dot.gov/index.htm. [Accessed: Feb. 12, 2025].

[3] IEEE, “IEEE Code of Ethics,” IEEE Corporate Governance, [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: Feb. 12, 2025].

[4] ACM, “ACM Code of Ethics,” ACM, [Online]. Available: https://www.acm.org/code-of-ethics. [Accessed: Feb. 12, 2025].

[5] IEEE, “IEEE Citation Guidelines,” IEEE Dataport, [Online]. Available: https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf. [Accessed: Feb. 12, 2025].