Weather-Resilient Camera System for Autonomous Vehicles

Design Document

Team #50

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1 Introduction

1.1 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.

1.2 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). The CNN, optimized for low-power environments, operates on an attached computer, enabling real-time raindrop detection on embedded hardware. Upon detecting rain, the system applies a wiping mechanism 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 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 12V 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 combination of advanced machine learning and targeted physical interventions—such as whipping mechanisms 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.

1.3 Visual Aid

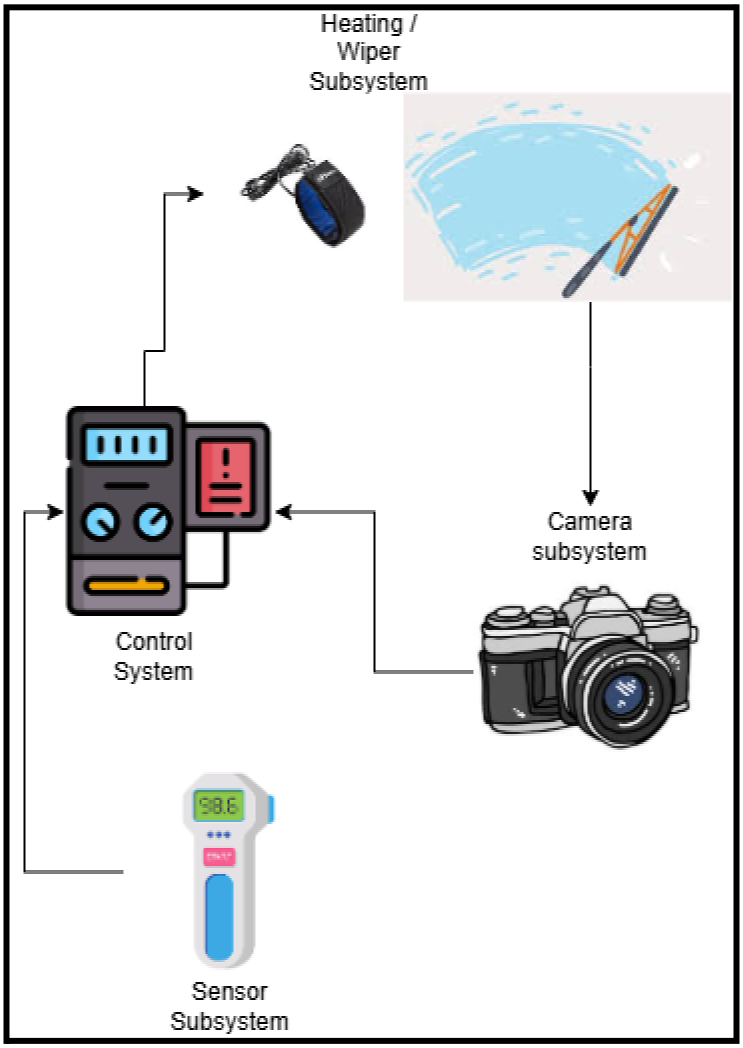

Figure 1: Visual Aid

1.4 High Level Requirements List

- The system must detect raindrops and ice obstructions with at least 75% accuracy using the CNN 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 12V battery, ensuring stable performance across all components without significant degradation in functionality, which is crucial for long-duration drives.

2 Design

2.1 Physical Design

The system consists of a protective enclosure, a PCB assembly, and a camera module. The enclosure is designed to house both the PCB and the camera, ensuring durability and protection from environmental factors. The PCB is securely mounted inside the enclosure, with external ports for power and data communication. The camera is positioned within a transparent container, allowing for unobstructed image capture while being shielded from environmental conditions.

To facilitate the cleaning mechanism, the PCB enclosure is directly attached to the transparent camera housing. This design allows for seamless integration of the motor and wiper system, ensuring efficient removal of raindrops or debris from the camera's field of view. The motor extends from the PCB enclosure, positioned to drive the wiper across the transparent cover of the camera housing. Below are the dimensions for the motor, which is strategically placed to maximize cleaning effectiveness while maintaining a compact and weather-resistant design.

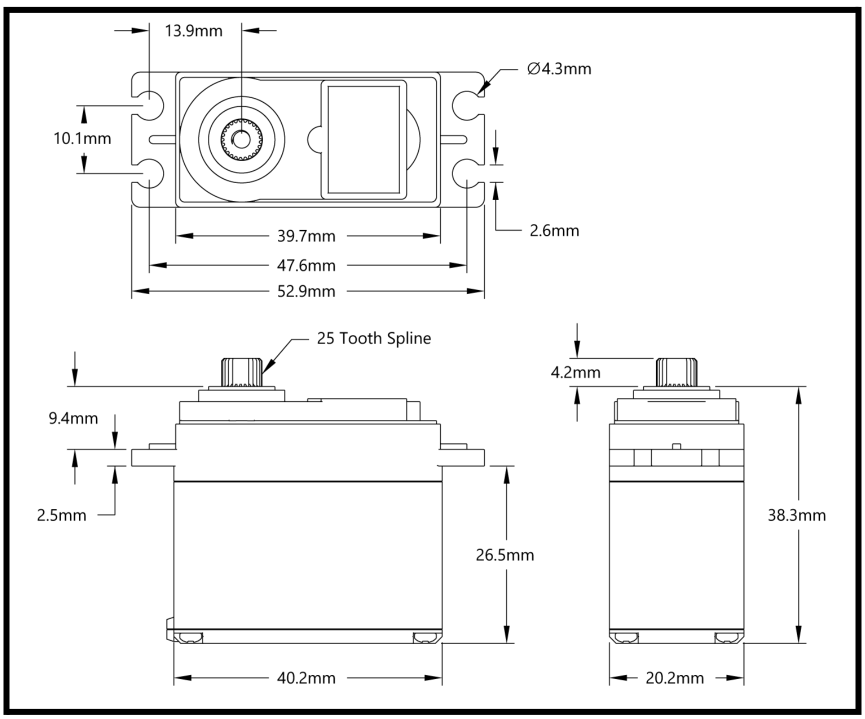

Figure 2.1: HS-318 Servo Motor Dimensions

2.2 Block Diagram

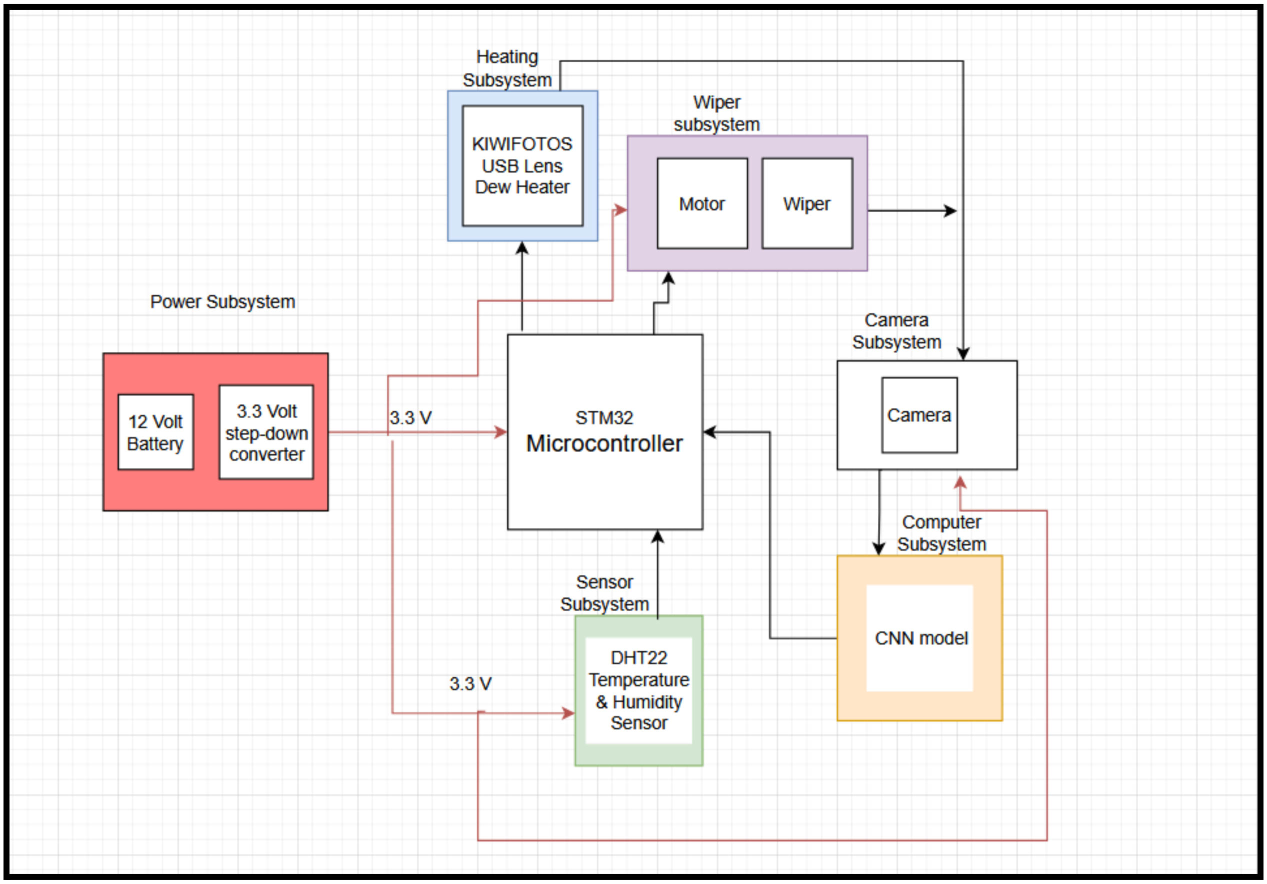

Figure 2.2: Block Diagram

2.3 Subsystem Overview & Block Diagram Requirements

2.3.1 The Camera Subsystem

The Camera Subsystem is responsible for providing a clear and uninterrupted imaging feed crucial for vehicle safety. It is built around the USB CAMERA FOR RASPBERRY PI AND DFRobot FIT0701, which captures the visual data used both for routine operation and for detecting precipitation. A key design requirement is to maintain the camera at an operating temperature of approximately 40°F—typically within a range of about 40°C to 42°C—to prevent condensation or frost that could obstruct the box surrounding the lens while it is raining. This subsystem connects with the sensor subsystem, which monitors environmental conditions and informs temperature management strategies, as well as the computer subsystem, which supplies a regulated voltage at 4.75- 5.25V. In addition, it interfaces with the microcontroller and computer subsystems again that process the camera feed and trigger any necessary corrective actions, ensuring that the camera remains dry and clear in adverse weather conditions.

Table 1: The Camera Subsystem - Requirements & Verification

Requirements	Verification
• The FIT0701 camera must receive 5 +/- .25 V	• Supply voltage from the power subsystem to just the camera • Use a voltmeter to measure the voltage
• The FIT0701 must deliver the correct data to the computer as well as the camera feed	• Utilizing the CNN model, we will implement the camera data and verify that the outputs are as expected (verify correct images are outputted). • Using software on the computer such as openCV we will bring up the camera feed

2.3.2 The Heating Subsystem

The Heating Subsystem is dedicated to preventing ice buildup on the camera lens by providing localized, controlled thermal energy. Central to this subsystem is the lens heater, which is designed to be mounted directly inside the box around the camera. When ice formation is detected over the camera, the heater is activated to raise the lens temperature sufficiently to melt the ice, thereby allowing the wiper to subsequently clear any residual obstruction. The heating element used in this design is a 5 V DC, 750 mA heating pad (SparkFun COM-11288), which ensures that the delivered current and voltage are within the required operational parameters for rapid and efficient thawing. This subsystem connects to the microcontroller, which issues the control signal to activate the heater based on environmental input, and it receives power from the regulated 4.75- 5 V supply provided by the power subsystem. This quantitative integration of voltage and current control directly supports the high-level requirement of maintaining a dry and clear camera, ensuring that the imaging system remains reliable under icy conditions.

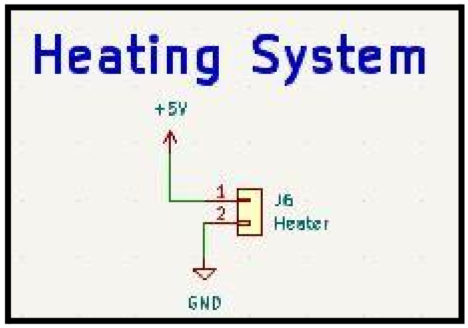

Figure 3: Heating System Schematic

Table 2: The Heating Subsystem - Requirements & Verification

Requirements	Verification
• The SparkFun COM-11288 must receive 5 +/- .25 V	• Supply voltage from the power system from the power system to the heating pad • Utilize a voltmeter to make sure voltage is the expected value
• There must be at most 750 mA delivered to the SparkFun COM-11288	• Utilize a multimeter to measure the current at the input node
• The SparkFun COM-11288 must be able to reach 20° C in at least 30 seconds	• Use a thermometer to take the temperature and ensure that this heat level is reached within the time limit

2.3.3 The Sensor Subsystem

The Sensor Subsystem continuously monitors the ambient and lens temperatures using a Waterproof Digital Temperature Sensor (DFRobot DFR0198) that operates on a regulated 3.15 -3.4 V supply provided by the power subsystem. This sensor provides real-time digital readings that are critical for detecting when the temperature falls near freezing. When temperatures drop below -1 - 0°C, the sensor immediately alerts the microcontroller, which in turn activates the heating subsystem. Once activated, the heating element raises the lens temperature to maintain it within the target range of 20°C to 22°C, ensuring that the camera remains free of ice and condensation. This precise thermal monitoring and response directly support the high-level requirement of delivering a clear, unobstructed imaging feed for safe autonomous vehicle operation.

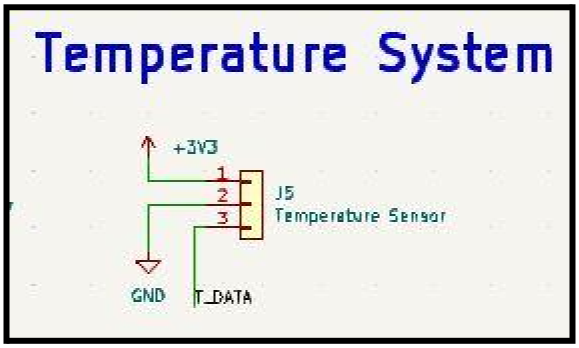

Figure 4: Temperature Sensor System Schematic

Table 3: The Sensor Subsystem - Requirements & Verification

Requirements	Verification
• The DFRobot DFR0198 temperature sensor must receive 3.3+/-.1 V	• Supply voltage from the power system from the power system to the DFRobot DFR0198 temperature sensor • Utilize a voltmeter to make sure voltage is the expected value
• The DFRobot DFR0198 temperature sensor must deliver the correct values of temperature from the temperature sensor.	• By using UART through the TX/RX pins on the STM32 microcontroller and software on a computer such as PuTTY the data received by the STM32 Microcontroller will be recorded and manually verified.

2.3.4 The Power Subsystem

The Power Subsystem is designed to deliver a stable and regulated power supply to the microcontroller, sensor, and heating subsystems, as illustrated in Figure 5 of the design document. It begins with a 12 V 2400 mAh AA Ni-MH battery pack, which under load typically provides between 11.5 V and 12.5 V. This 12 V source is then conditioned using voltage regulators to create distinct power rails required by the connected subsystems. Specifically, a 3.3 V step-down converter, —based on the Diodes Incorporated AP2112K-3.3TRG1, is used to supply a regulated voltage, generally maintained in the range of approximately 3.1 V to 3.5 V, to power the microcontroller and sensor subsystems. In addition, a separate 5 V linear regulator (Rohm Semiconductor BD50FC0FP-E2) provides a stable 5 V output to the heating subsystem, which utilizes a 5 V DC heating pad rated at 750 mA as well as the wiper subsystems. This clear delineation of voltage levels ensures that each subsystem receives the precise voltage required for reliable operation, directly contributing to the overarching goal of maintaining a dry and clear camera.

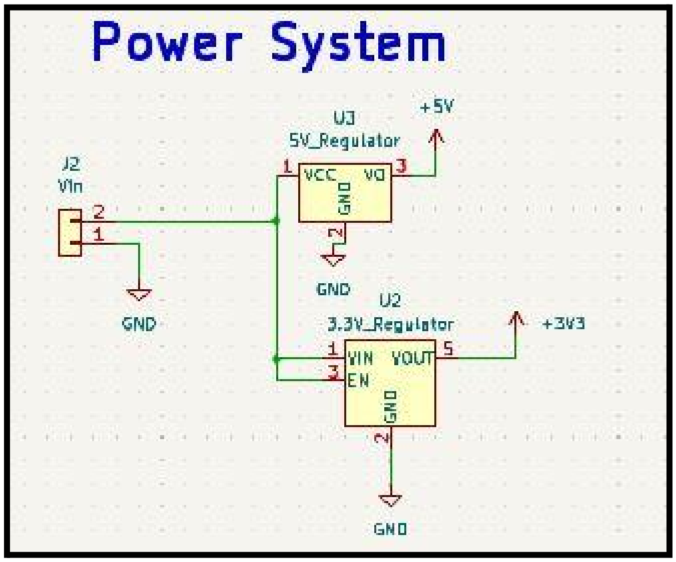

Figure 5: Power System Schematic

Table 4: The Power Subsystem - Requirements & Verification

Requirements	Verification
• The AA Ni-MH battery pack must provide 12 +/- .5 V	• Utilize a voltmeter to measure the voltage of the AA Ni-MH battery pack
• The AP2112K-3.3TRG1 voltage regulator must output 3.3+/-.2 V • The AP2112K-3.3TRG1 voltage regulator must have a temperature range of -40°C to 85°C	• Utilize a voltmeter to measure the voltage of the AP2112K-3.3TRG1 voltage regulator • Use a thermometer to take the temperature to ensure that the regulator stays between -40°C to +85°C
• The BD50FC0FP-E2 voltage regulator must output 5+/-.25 V as well as a current of at least 750 mA • The BD50FC0FP-E2 voltage regulator must have a temperature range of -25°C to 85°C	• Utilize a voltmeter to measure the voltage of the D50FC0FP-E2 voltage regulator • Utilize a multimeter to measure the current output of the D50FC0FP-E2 voltage regulator • Use a thermometer to take the temperature to ensure that the regulator stays between -25°C to +85°C

2.3.5 The Microcontroller Subsystem

The Microcontroller Subsystem serves as the central processing unit that connects and manages communication between all subsystems to implement the weather-resilient camera solution. The microcontroller used in this design is the STM32F103C8T6, as shown in Figure 6 of the design document. This microcontroller is responsible for processing sensor data, controlling the heating system, and ensuring the overall coordination of the camera system.

The microcontroller operates on a 3.3V power supply, which is regulated from the 12V battery via a step-down converter. It receives input from the sensor subsystem, which monitors environmental conditions such as temperature, and based on this data, it decides when to activate the heating subsystem to maintain the camera's temperature within the specified range of 20°C to 22°C. Additionally, the microcontroller interacts with the power subsystem, ensuring stable voltage regulation across all connected components.

The microcontroller system schematic in Figure 6 provides an overview of the electrical connections. It features multiple capacitors for voltage stabilization, a crystal oscillator for clock synchronization, and various GPIO pins for interfacing with peripherals such as sensors and heaters. The system also includes boot mode selection circuits, which allow for firmware updates or debugging.

By integrating control logic for temperature regulation and heating activation, the microcontroller ensures that the camera remains functional in adverse weather conditions. Its real-time processing capability enables efficient decision-making, contributing to the overall goal of maintaining a clear and reliable imaging system.

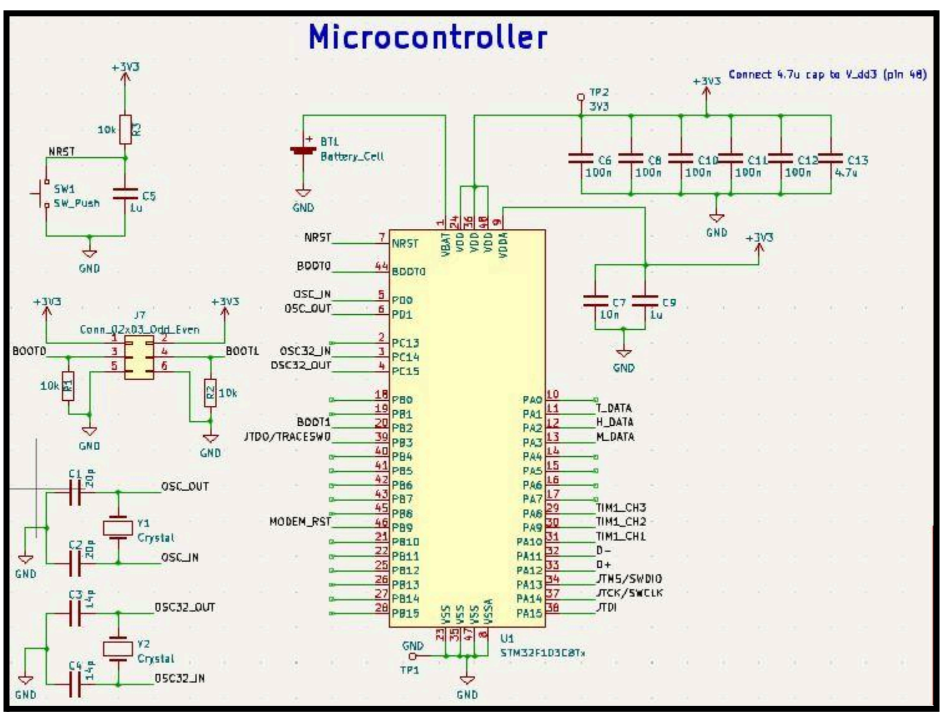

Figure 6: Microcontroller System Schematic

Table 5: The Microcontroller Subsystem - Requirements & Verification

Requirements	Verification
• The STM32F103C8T6 microcontroller must receive 3.3 +/- .15 V	• Supply voltage from the power system from the power system to the STM32F103C8T6 • Utilize a voltmeter to make sure voltage is the expected value
• The STM32F103C8T6 microcontroller must receive and analyze the data from the CNN-Modal and the OpenCV system.	• When rain is detected and there is no blockage, the HS-318 servo motor will complete a full sweep range within .2 to .3 seconds per cycle
• The STM32F103C8T6 microcontroller must in general output 3.3+/- .15 V from a pin.	• Utilize a voltmeter to make sure voltage is the expected value at the gate of two MOSFETs • Use a voltmeter to confirm the output of MOSFET circuit is 0V
• The STM32F103C8T6 microcontroller must receive and analyze the data from the temperature sensor	• When the temperature drops below 0° C and there is blockage detected from the OpenCV System, the STM32 Microcontroller must stop sending a voltage of 3.3 +/- .15 V to the gate of a MOSFET • Use a voltmeter to confirm the output of MOSFET circuit is 5V +/-.25V

2.3.5 The Wiping Subsystem

The Wiping Subsystem is responsible for physically clearing the camera lens of water droplets, and ice, ensuring an unobstructed view for the imaging system. This subsystem consists of a servo motor (HS-318) that drives a mechanical wiper to sweep across the lens when activated. The wiper is essential for maintaining camera clarity in situations where heating alone is insufficient to remove obstructions.

The servo motor operates on an approximately 5V power supply but can operate on 4.8 to 6 V and is activated when lens obstructions are detected. The wiping mechanism completes a full sweep within a range of approximately 0.2 to 0.3 seconds per cycle, ensuring that the camera remains clear without significantly disrupting its field of view. The power for the motor is provided by the power subsystem, which delivers a regulated 5V output to ensure consistent operation.

This subsystem interacts with the microcontroller subsystem, which determines when wiping is necessary based on environmental conditions detected by the sensor subsystem. The wiper arm is mechanically positioned to cover the camera lens effectively, ensuring complete clearance in one or two passes. By integrating with the other subsystems, the Wiping Subsystem ensures that the camera remains functional in adverse weather, directly contributing to the overall goal of maintaining a reliable imaging system.

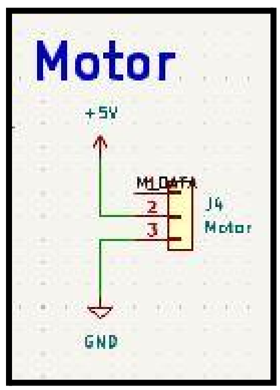

Figure 7: Motor System Schematic

Table 6: The Wiping Subsystem - Requirements & Verification

Requirements	Verification
• The HS-318 Servo Motor must receive 5+/-.25 V	• Supply voltage from the power system from the power system to the HS-318 Servo Motor • Utilize a voltmeter to make sure voltage is the expected value
• The HS-318 Servo Motor must have a wiper attached and complete a full sweep in .2 to .3 seconds	• Ensure the attachment of wiper through a small stress test of tugging on the attachment. • Time the speed of the HS-318 Servo Motor.
• The HS-318 Servo Motor must stay between -20°C to +60°C	• Once running, use a thermometer to take the temperature to ensure that the servo motor stays between -20°C to +60°C

2.3.7 The Computer Subsystem

The Computer Subsystem is responsible for processing the camera feed to detect rain and ice obstructions using a convolutional neural network (CNN). It continuously analyzes the video data to determine when precipitation or ice is affecting visibility. When an obstruction is detected, the system communicates with the Microcontroller Subsystem, which then decides whether to activate the Heating Subsystem to melt ice or the Wiping Subsystem to remove water droplets. By handling real-time image processing, the Computer Subsystem ensures the camera remains functional in adverse weather conditions.

Unlike other components, the Computer Subsystem does not rely on the Power Subsystem, as it is powered by its own dedicated battery, which operates within a range of 11.5V to 12.5V. It interfaces directly with the Camera Subsystem via a USB 2.0 connection, allowing it to receive and process video data. Additionally, it connects with the Microcontroller Subsystem, sending signals based on detected obstructions to trigger appropriate corrective actions. Through its independent power source and seamless integration with other subsystems, the Computer Subsystem plays a vital role in maintaining a clear and reliable camera feed.

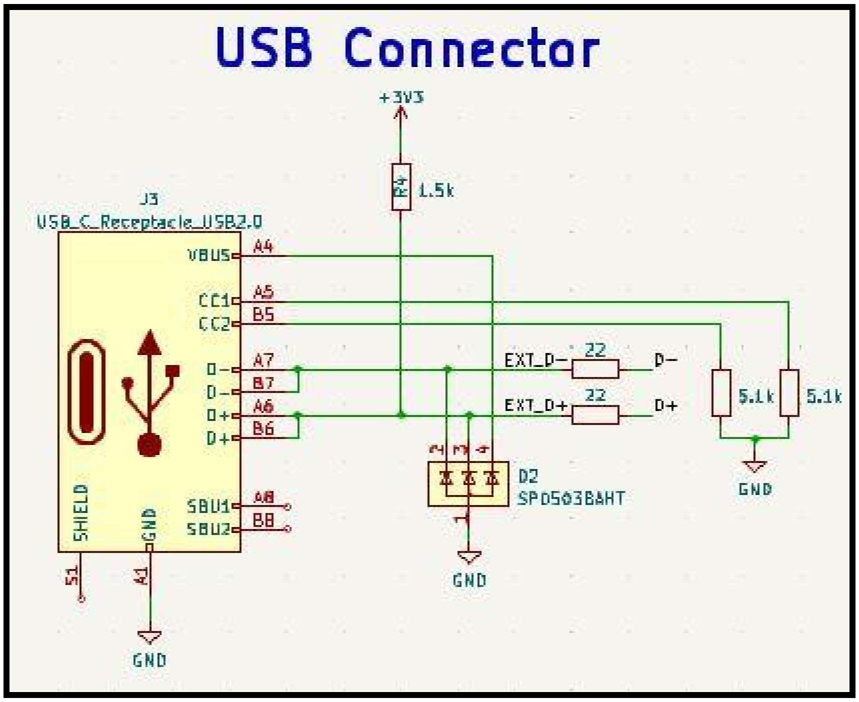

Figure 8: USB Connector Schematic

Table 7: The Computer Subsystem - Requirements & Verification

Requirements	Verification
● A computer must connect to the STM32 Microcontroller through the USB Connector	● Using the device manager on the computer will confirm if the STM32 Microcontroller is connected.
● The STM32 microcontroller must receive data from the CNN model and OpenCV system	● By using the UART through the TX/RX pins and software on the computer such as PuTTY the data received by the STM32 Microcontroller will be recorded and manually verified. ●

2.4 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 (ω) 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.

3 Cost & Schedule

3.1 Cost

3.1.1 Labor

We will use the following formula to calculate labor costs for each member of our group:

($/hour) x (number of workers) x hours to complete = TOTAL

For salary, ($/hour), we are estimating this using the data from the UIUC ECE website. The most recent year displayed, (AY 21-22) shows that the average EE annual salary is $87,769 and the average CE annual salary is $109,176. We have averaged this $98,472.5 per year. Assuming 40 hour work weeks, with 21 days off per year, this becomes $50.24 per hour.

For the number of workers, we are including the three group members, hence the number of workers = 3.

For hours to complete, we are estimating that we will work 12 hours per week each, across 8 weeks of work, totaling 96 hours of work each.

Plugging in the numbers, we get that the total labor cost will be $14,469.12

3.1.2 Parts

Description	Manufacturer	Part #	Quantity	Cost
12V 2400mAh AA NI-MH Battery Pack with Standard Tamiya Connector	CBB	28RFLNK	1	$0.17
USB CAMERA FOR RASPBERRY PI AND	DFRobot	FIT0701	1	$9.90
WATERPROOF DIGITAL TEMPE	DFRobot	DFR0198	1	$6.90
IC REG LINEAR 3.3V 600MA SOT-25	Diodes Incorporated	AP2112K-3.3TRG1	1	$0.56
IC REG LINEAR 5V 1A TO252	Rohm Semiconductor	BD50FC0FP-E2	1	$1.77
Microcontroller - IC MCU 32BIT 64KB FLASH 48LQFP	STMicroelectronics	STM32F103C8T6	1	$6.01
NUCLEO-64 STM32F401RE EVAL BRD	STMicroelectronics	NUCLEO-F401RE	1	$13.82

Description	Manufacturer	Part #	Quantity	Cost
HS-318 Servo-Stock Rotation	ServoCity	HS-318	1	$18.78
CONN RCP USB2.0 C 6POS SMD RA	Molex	2171750001	1	$0.75
HEATING PAD 5VDC 750MA 5X10CM	SparkFun Electronics	COM-11288	1	$4.50
JUMPER WIRE M/M 6" 20PCS	SparkFun Electronics	PRT-12795	1	$2.10
MOSFET - IC DUAL COMPL PAIR W/INV 14-DIP	Texas Instruments	CD4007UBE	2	$0.65
LED RED (5MM)	Broadcom Limited	HLMP-3301	1	$0.39
RES 100K OHM 1% 1/4W 1206	YAGEO	RC1206FR-07100KL	3	$0.10
RES 22 OHM 1% 1/4W 1206	YAGEO	RC1206FR-0722RL	2	$0.10
RES 5.1K OHM 1% 1/10W 0603	YAGEO	RC0603FR-105K1L	2	$0.10
RES 1.5K OHM 1% 1/4W 1206	YAGEO	RC1206FR-131K5L	1	$0.10
RES 10K OHM 1% 1/4W 1206	YAGEO	RC1206FR-1010KL	3	$0.10
TVS DIODE 5.5VWM 8.5VC SOT1434	Littelfuse Inc.	SP0503BAHTG	1	$0.70
CAP CER 0.1UF 50V Z5U RADIAL	Vishay Beyschlag/Draloric/BC Components	1C20Z5U104M050B	5	$0.60
CAP CER 4.7UF 50V X5R 1206	Murata Electronics	GRM319R61H475KA12D	1	$0.24
CAP CER 1UF 25V X7R 0603	Samsung Electro-Mechanics	CL10B105KA8NNNC	2	$0.06
CAP CER 20PF 250V C0G/NP0 0603	KYOCERA AVX	600S200FT250XT4K	2	$1.85
CAP CER 10000PF 16V X7R 0402 (10nF)	Murata Electronics	GRM155R71C103KA01D	1	$0.08
CRYSTAL 8.0000MHZ 20PF TH	ECS Inc.	ECS-080-20-4X-DU	1	$0.54
6" M/M Jumper Wires ONE WIRE price	SparkFun Electronics	PRT-12795	2	$0.17
CONN HEADER VERT 6POS 2.54MM	Adam Tech	PH2-06-UA	1	$0.10
Machine Shop Labor Hours	*estimated*	*estimated*	10	$40/hr
				$476.87

Figure 9: Itemized list of Components and Costs

3.1.3 Grand Total

The total cost is our “labor” cost added to our “parts” cost which totals to: $14,945.99

3.2 Schedule

Week	Task(s)	Person
March 3rd - March 9th	• Design Document	Adam
	• Finalize microcontroller code for breadboard demo	Deyvik
	• Prepare parts for breadboard demo	Jacob
March 10th - March 16th	• Finalize PCB design and place order	Adam
		Deyvik
		Jacob
March 17th - March 23rd	Spring Break	
March 24th - March 30th	• Test PCB and revise design	Adam
	• Finish CNN code	Deyvik
	• Solder first Round PCB	Jacob
March 31st - April 6th	• Individual Progress Reports • Continue to revise any code or PCB design as needed • Place order for final PCB	Adam
		Deyvik
		Jacob
April 7th - April 13th	• Continue to revise any code or PCB design as needed	Adam
		Deyvik
		Jacob
April 14th - April 20th	• Prepare for mock/final demo	Adam
		Deyvik
		Jacob
April 21st - April 27th	Mock Demo	
April 28th - May 4th	Final Demo	

Figure 10: Schedule for Project Progression

4 Ethics and Safety

4.1 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.

4.2 Safety

Safety is a primary concern in the design and implementation of this system. To mitigate potential hazards, several design decisions and procedures have been put in place. First, the project uses low-power components, reducing the risk of electrical hazards. The PCB is enclosed in a weather-resistant, insulated casing to prevent accidental exposure to live electrical connections. All power supply connections are routed through dedicated protective circuits to prevent overcurrent and short-circuiting.

Additionally, the motor and wiper system are designed with safety in mind. The motor is housed within the PCB enclosure, preventing any moving parts from being exposed to the user. To further protect users, the enclosure is secured with screws to prevent accidental access to internal components while the system is operating. The camera housing is transparent yet secure, preventing any risk of contact with the camera or other sensitive components. Finally, as the project does not involve high-power electronics, chemicals, or other hazardous materials, the main safety concern is ensuring that the system is properly weatherproofed to avoid any potential exposure to water or debris, which could cause electrical malfunctions or damage.

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 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.

5 References

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