UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Weather-Resilient Camera System for Autonomous Vehicles

Group 50

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Introduction

Introduction — Meet the Team & Project

Team 50: Weather-Resilient Camera System for Autonomous Vehicles

- **Team Members**
  - **Deyvik Bhan** – Computer Engineering
  - **Adam Shore** – Computer Engineering
  - **Jacob Camras** – Electrical Engineering
- **Project Goal**: Build an automated system that maintains camera visibility during adverse weather.
- **Key Features**:
  - Detects rain or freezing conditions.
  - Responds to maintain visibility.
- **Purpose**: Ensure reliable vision for driver-assist and autonomous technologies.

Objective — What Problem Are We Solving?

The Challenge:

- Camera systems in autonomous and driver-assist vehicles are critical for safety.
- Ice formation or raindrop accumulation on lenses compromises visibility.
- This can lead to reduced object detection or navigation errors

Why It Matters:

- Obstructed cameras impair lane detection, collision detection, and emergency braking.
- Manual cleaning isn't feasible during operation.
- Passive solutions like coatings or basic heaters are insufficient in dynamic or freezing conditions.

Our Goal:

- Create a self-sustaining camera system that:
  - Detects rain or ice obstructing the lens.
  - Automatically restores visibility using active heating or wiping.
- Enable safe, uninterrupted performance in rainy and snowing/freezing conditions.

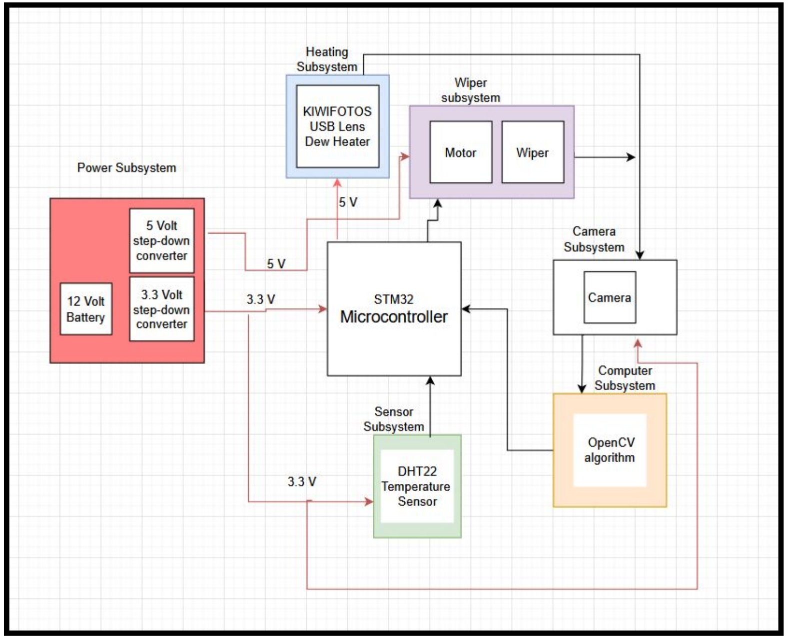
Design

Subsystems

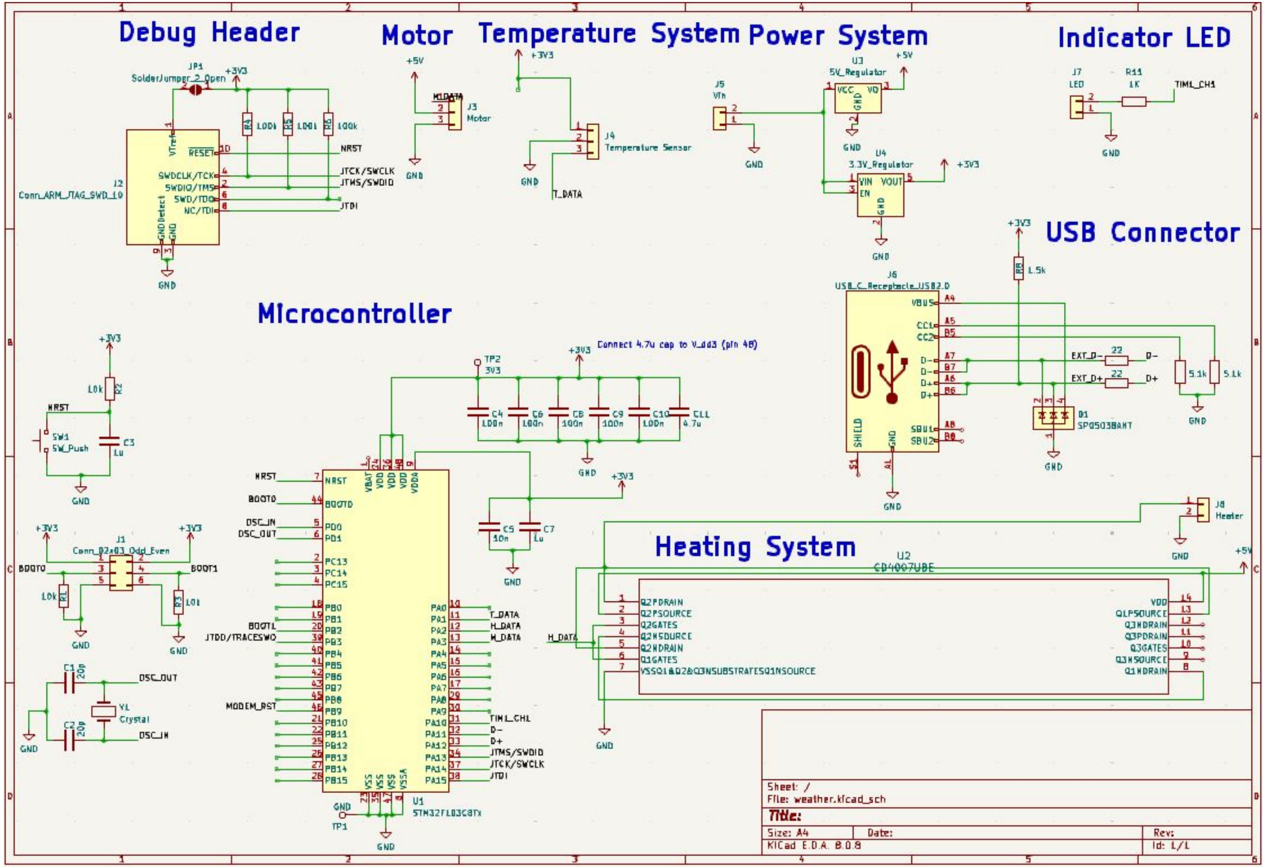
Seven Subsystems: Power, Heating, Wiper, Camera, Computer, Sensor, and Microcontroller

Original plan

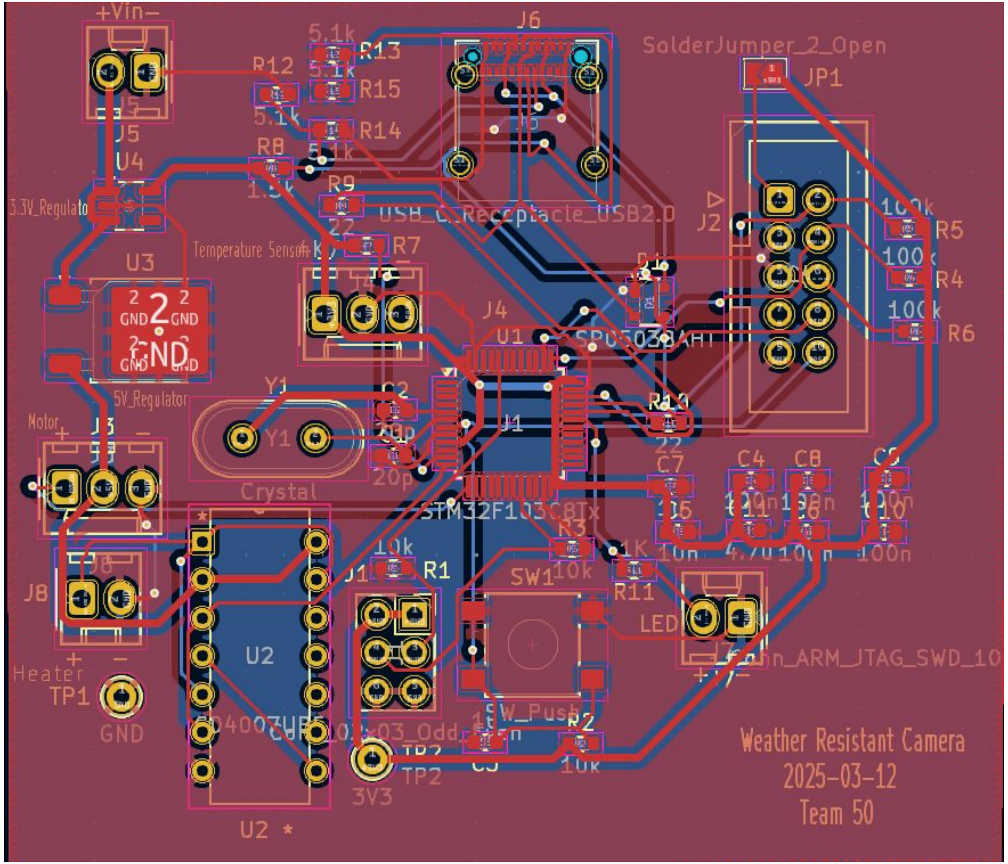
Use convolutional neural network (CNN) with camera for raindrop detection which activates wiper system through microcontroller. If temperature is at zero degrees celsius the heater will turn on to prevent ice formation.



PCB Design


Debug Header
Motor
Temperature System
Power System
Indicator LED
USB Connector
Microcontroller
Heating System
Connect 4.7u cap to V_dd3 (pin 48)
Sheet: /
File: weather.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 8.0.8
Id: 1/1

PCB Schematic

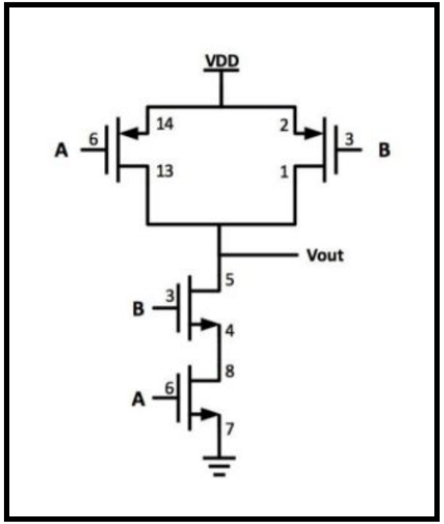


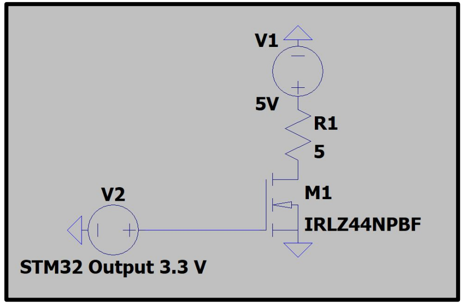
Issues

The CNN model was too slow for the computing resources that we had and the distance between the lens of the camera and the window was too close. The MOSFET circuit did not output enough current due to the limitation of the MOSFET we were using.

Fixes

-Went from CNN model to Open Source Computer Vision Library (OpenCV) algorithm
-Changed MOSFET circuit and actual MOSFET.(CD4007UBE to IRLZ44N)





Camera Subsystem

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 OpenCV algorithm, 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

Computer Subsystem

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 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.

Power Subsystem

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

Heating Subsystem

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 least 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

Wiping Subsystem

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

Temperature Sensor Subsystem

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.

Microcontroller Subsystem

The Microcontroller Subsystem - Requirements & Verification

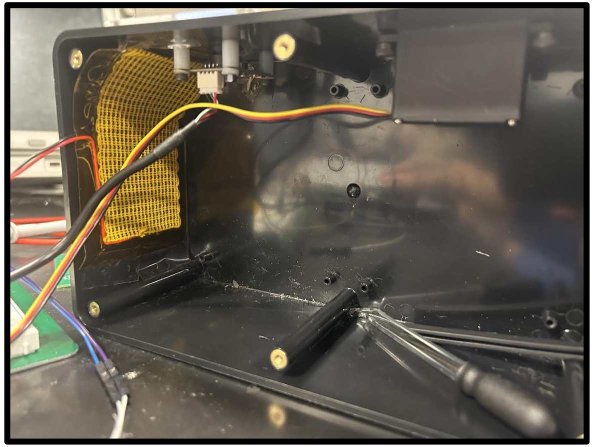
Requirements	Verification
• The STM32F103C8T6 microcontroller must receive 3.3 +/- .15 V	• Supply voltage from the power system from the power system to the STM32F103C8T6 • Utilize a voltmeter to make sure voltage is the expected value
• The STM32F103C8T6 microcontroller must receive and analyze the 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

Final Product

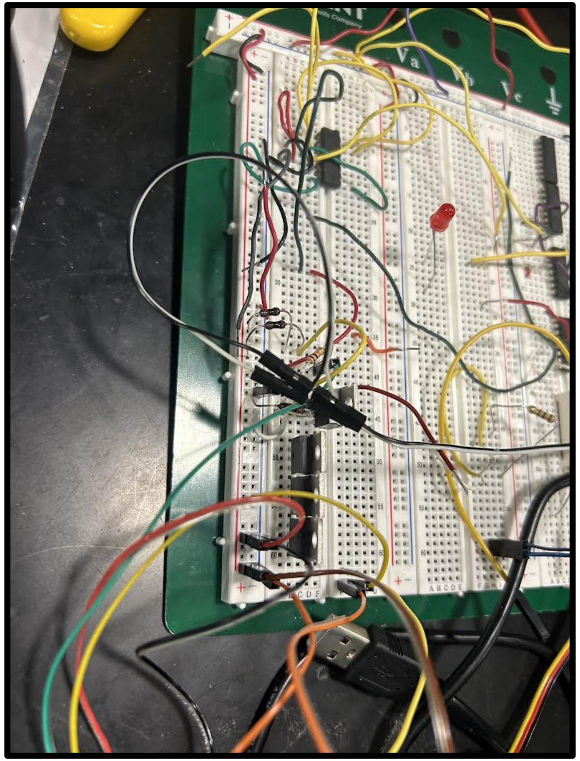
Final Product

Front

Inside



Breadboard



Functional Test Results

Raindrop Detection Accuracy

100 Total Trials	**Raindrop Applied**	**Raindrop NOT Applied**
Raindrop Detected	**38 (True Positive)**	**1 (False Negative)**
Raindrop NOT Detected	**12 (False Positive)**	**49 (True Negative)**

- Correctly detected raindrop(s) 38 / 50 trials (76%)
- Correctly detected no raindrop(s) 49 / 50 trials (98%)
- Cumulatively correctly detected raindrop(s) 87 / 100 trials

Total Evaluated Accuracy: 87%

Functional Test Results

Image Detection

Initially, the image is grabbed directly from the attached camera feed, allowing the computer to visualize and analyze the surroundings.

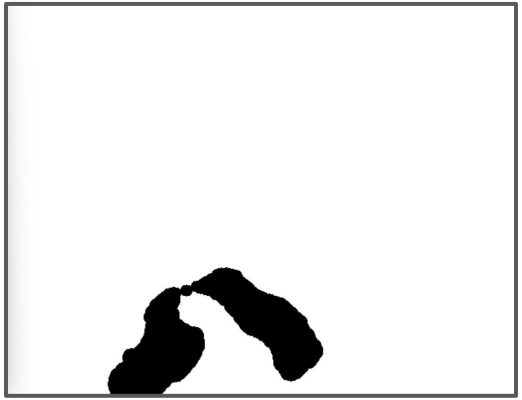
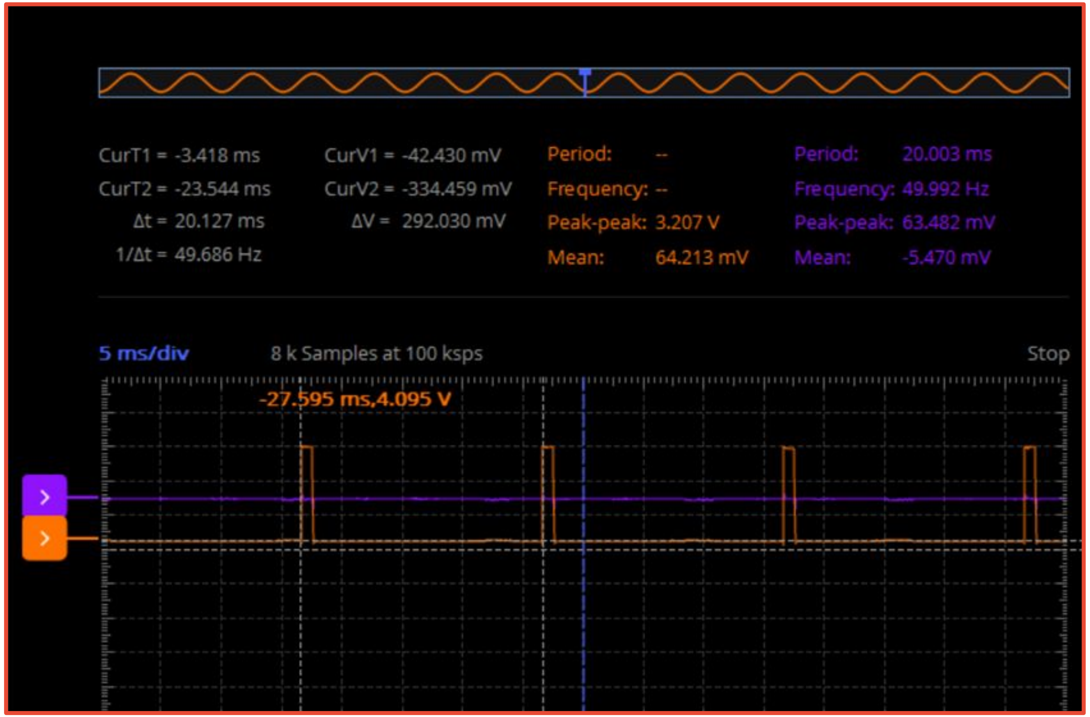


Image Analysis

After the image is grabbed, our program outlines the raindrop in the form of a black and white image. The percent of black pixels (water) is analyzed and if it is above the threshold of total pixels (5%), the wiper is triggered.

PWM Generation

The microcontroller generates a PWM with a 20 ms period and a varying duty cycle of 5 to 10% wave which powers and controls the movement of the motor.



Successes, Challenges, and failures

Successes

- OpenCV algorithm
- heating subsystem
- sensor subsystem
- wiper subsystem
- power subsystem
- microcontroller subsystem

Challenges

- Soldering PCB
- power subsystem
- wiper subsystem
- Design

Failures

- Failed to get working PCB

Conclusion and Future Improvements

Conclusions — What We Learned

Lessons Learned:

- Designing for real-world weather emphasized the importance of **fast, reliable obstruction removal**.
- Integrating environmental sensors with computer vision allowed for **accurate detection of ice and raindrops**, minimizing false activations.
- Coordinating system response to match weather patterns in real time was essential to maintaining camera clarity.

If we were to redesign:

- **Relocate the camera slightly farther from the clear protective plate**, reducing visual interference from raindrops and improving computer vision accuracy.
- Consider **tighter sealing** to prevent water seepage and improve long-term durability in storm-like conditions.
- **Use a lower-friction wiper mechanism** to reduce wear and ensure smoother, more consistent lens clearing.

Recommendations — Future Work

1. Environmental Expansion

- Add **fog detection** to address visibility loss beyond just physical blockage.
- Implement **dust and debris detection**, particularly for environments with dry roads or construction zones.

2. Smarter Integration

- Merge sensor readings and camera input into a unified **AI-based decision model** that classifies obstructions (e.g., rain, ice, fog, dust).
- Integrate with the vehicle's onboard computer for **coordinated cleaning and visibility management** across all camera systems.

Recommendations — Future Work Cont.

3. System Enhancements

- Apply a **hydrophobic nano-coating** to reduce the need for physical wiping.
- Introduce **adaptive cleaning behavior** based on vehicle speed, precipitation rate, and historical data.

4. Long-Term Vision

- Expand to **multi-camera configurations** for full-vehicle coverage.
- Explore integration with **vehicle diagnostics systems** to alert the user or initiate maintenance when obstructions persist.

Thank You!

Questions?

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The Grainger College of Engineering

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