AUTOMATIC DEFOGGING SYSTEM **MIN 300 LBP**

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Abstract

This report presents the development and validation of an automatic defogger system designed to enhance visibility and safety by mitigating fog formation on glass surfaces. Leveraging principles of heat transfer and temperature control, our prototype employs a combination of sensors, relays, and heating elements to elevate the glass temperature above the dew point, thus preventing condensation and fogging. Through rigorous experimentation and numerical simulation, we demonstrate the efficacy of our defogger system in achieving rapid fog removal, outperforming natural conditions by nearly fivefold. The successful implementation of our prototype offers promising implications for diverse applications requiring fog mitigation solutions, underscoring its potential to improve visibility and safety in various settings.

Introduction

The pervasive issue of fog accumulation on glass surfaces poses significant challenges. across various industries, from automotive to aerospace, affecting visibility and safety. Traditional defogging methods often involve manual intervention or rely on external devices, which may not provide optimal solutions in real-time scenarios. Recognizing the critical need for an efficient and automated solution, our team embarked on developing an innovative approach to combat fogging on glass surfaces. The fundamental principle driving our project lies in the understanding of dew point temperature and its relationship with fog formation. Fog occurs when moist air comes into contact with a surface whose temperature is below the dew point temperature of the surrounding air. This phenomenon leads to condensation, resulting in the formation of fog on the surface.

Our idea revolves around the utilization of heat to elevate the temperature of the glass surface above the dew point temperature, By implementing a system capable of detecting fogging conditions and activating heat dissipation mechanisms, we aim to develop an automatic defogger that ensures clear visibility under diverse environmental conditions.

Validation of Fog Formation

To validate the occurrence of fog formation and its relationship with temperature variations, we explored several methodologies. Initially, we experimented with image processing techniques to quantify visibility impairment caused by fog. However, recognizing the limitations of this approach, particularly in low-light conditions, we transitioned to conducting laboratory experiments to directly observe the interplay between temperature changes and fog formation.

Lab Based Experiment

In our laboratory-based experiment, we constructed a controlled environment to simulate fogging conditions at the cold storage present in the solar lab at Mechanical and Industrial Engineering Department IIT Roorkee. Utilizing a glass surface as our test substrate, we subjected it to varying temperatures while monitoring the ambient atmospheric conditions. Through meticulous observation, we established a critical finding: fog condensation commenced when the temperature of the glass dipped below the dew point temperature (DPT) of the surrounding atmosphere.

Temperature Variation and Fog Formation

Our experimental results revealed a distinct correlation between temperature fluctuations and fog formation. Initially, as the temperature of the glass surface gradually decreased, it approached the dew point temperature of the surrounding atmosphere. At this critical juncture, fog condensation commenced, leading to impaired visibility.

Upon reaching the dew point temperature threshold, we observed a noteworthy phenomenon: the temperature of the glass surface began to rise gradually, surpassing the dew point temperature. This temperature elevation initiated a defogging process, effectively mitigating the condensation and restoring clear visibility on the glass surface.

The laboratory-based experimentation provided invaluable insights into the dynamics of fog formation and the efficacy of temperature manipulation in mitigating its effects. These findings served as the cornerstone for the subsequent development of our automatic defogger system, guiding us towards the implementation of an efficient and reliable solution for real-world applications.

Fig 1 & 2: Validating the relation of Temperature and fogging at Cold Storage of MIED, IIT Roorkee

Defogging Mechanism Development

Initial Approach: Hot Air Blower

In our pursuit of crafting a robust defogging mechanism, our team initially deliberated on employing a hot air blower as the primary means to elevate the temperature of the glass surface. The underlying rationale driving this approach stemmed from the perceived efficacy of utilizing a direct heat source to swiftly raise the glass temperature beyond the dew point threshold. By implementing a hot air blower, we aimed to counteract fog condensation through rapid and substantial temperature elevation.

Reconsideration: Drawbacks of Hot Air Blower

However, upon conducting a thorough analysis of the proposed hot air blower method, we unearthed several inherent limitations that necessitated a reevaluation of our approach. Chief among these concerns was the unintended consequence of escalating the dew point temperature within the surrounding atmospheric environment. The introduction of hot air not only augmented the glass temperature but also inadvertently elevated the dew point temperature, exacerbating the fogging issue and rendering the solution counterproductive. Moreover, the utilization of a hot air blower posed significant challenges in terms of energy consumption, as the continuous operation of the device necessitated substantial power input, thereby diminishing its practicality for sustained and widespread deployment.

Refined Strategy: Heating Strip via Conduction

In response to the identified shortcomings of the hot air blower method, our team embarked on a strategic reassessment aimed at devising a more refined and energy-efficient approach to defogging. After careful consideration, we proposed the adoption of a heating strip positioned in direct contact with the glass surface, thereby facilitating heat transfer through conduction. This innovative strategy represented a departure from conventional methods, leveraging the principles of thermal conduction to achieve targeted temperature elevation while minimizing the associated drawbacks.

The transition to a heating strip via conduction offered a myriad of advantages over the previous hot air blower method. By virtue of its direct contact with the glass surface, the heating strip facilitated precise temperature control and localized heating, thereby optimizing the defogging process while minimizing energy expenditure. Furthermore, the adoption of a heating strip promised to mitigate the adverse effects on the surrounding atmospheric conditions, ensuring a more sustainable and environmentally conscious solution to fog mitigation. Additionally, the inherent simplicity and reliability of the heating strip approach enhanced its suitability for integration into diverse applications requiring fog mitigation solutions.

In conclusion, the evolution of our defogging mechanism development process underscored the iterative nature of problem-solving and the imperative of adapting to emerging challenges. The transition from the hot air blower to the heating strip via conduction represents a strategic refinement in our approach, guided by the principles of efficiency, sustainability, and operational efficacy. Moving forward, our team remains committed to advancing the frontiers of defogging technology, with a steadfast focus on delivering innovative solutions that empower enhanced visibility and safety across diverse environments.

Analytical Solution Formulation and Mathematical Modelling

Formulation of Analytical Solution

$$\boxed{\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{q}}{k} = \frac{\rho C_p}{k}\frac{\partial T}{\partial t}}$$ Heat Conduction Equation

In our quest to develop a comprehensive understanding of the temporal and spatial variation of the glass plate under the influence of heat flux, we embarked on formulating an analytical solution. Initially, we conceptualized the problem as a two-dimensional (2D) film, intending to capture the intricate dynamics of heat transfer across the surface. However, upon rigorous formulation of the governing equations and imposition of adiabatic boundary conditions on all three sides of the glass plate, we encountered discrepancies in our results, prompting a critical reassessment of our approach. Subsequent analysis revealed that the discrepancies observed in our 2D formulation stemmed from inherent complexities in capturing multidimensional heat transfer phenomena. In light of these challenges, we made the pivotal decision to reclassify the problem as a one-dimensional (1D) heat transfer scenario. By simplifying the problem domain to a single spatial dimension, we aimed to streamline the mathematical modelling process while retaining fidelity to the underlying physical principles governing heat transfer.

With the transition to a 1D problem established, we proceeded to develop a mathematical model to elucidate the temporal and spatial variation of the glass plate under the influence of heat flux. Leveraging the finite volume method, we implemented a numerical solution framework in MATLAB to simulate the dynamic evolution of temperature distribution along the length of the glass plate.

Simulation Setup and Boundary Conditions in MATLAB

In our MATLAB simulation, we initialized the 1D heat equation with an initial temperature of 6°C along the length of the glass plate. Adhering to the physical constraints of the problem, we enforced adiabatic boundary conditions on three faces of the glass plate to emulate real-world scenarios accurately. Additionally, we imposed a heat flux of 500W from one end of the glass plate, simulating the heat input mechanism, while applying a convective heat transfer boundary condition with a heat transfer coefficient (h) of 20W/m^2K on each side to account for heat dissipation.

The simulation results revealed compelling insights into the temporal and spatial variation of temperature distribution along the length of the glass plate. After 10 seconds of simulation, the minimum temperature along the length of the glass plate reached 10°C, surpassing the dew point temperature and effectively mitigating fog formation. This critical threshold marked the onset of defogging, validating the efficacy of our proposed approach in combating visibility impairment caused by fog condensation.

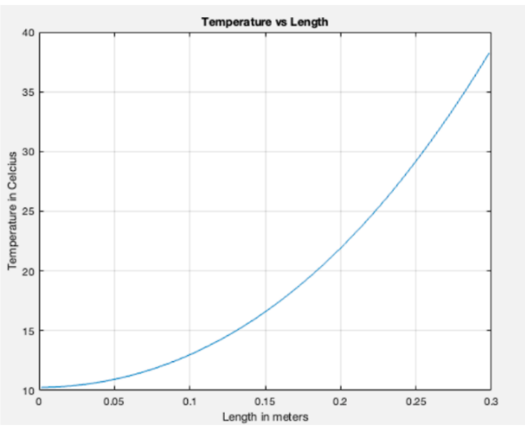

Fig 3: Spatial Variation of Glass Plate at t=10 seconds

Fig 4: Matlab script for 1D transient conduction using finite volume approach.

Finite Element Method (FEM) Simulation and Validation

To corroborate the findings obtained from the MATLAB simulation, we conducted a Finite Element Method (FEM) simulation using ANSYS Thermal Transient. The first step in this endeavour involved the design of a CAD model replicating the geometry of the glass plate under investigation. Leveraging SolidWorks, we meticulously crafted a CAD model representing a glass plate with dimensions of 30cm x 30cm x 0.5cm, ensuring fidelity to real-world dimensions and geometrical intricacies.

A critical aspect of FEM simulation is the generation of a high-quality mesh that facilitates accurate numerical approximation of the underlying physical phenomena. In our endeavor, we employed a hexagonal meshing scheme to discretize the CAD model into finite elements, ensuring optimal computational efficiency while preserving the structural integrity of the model. The mesh generation process entailed meticulous attention to detail, with 4,608 nodes strategically distributed across the model to capture localized variations in temperature and heat flux. Ant the material property assigned was of E-Glass, similar to what we performed our experiment on.

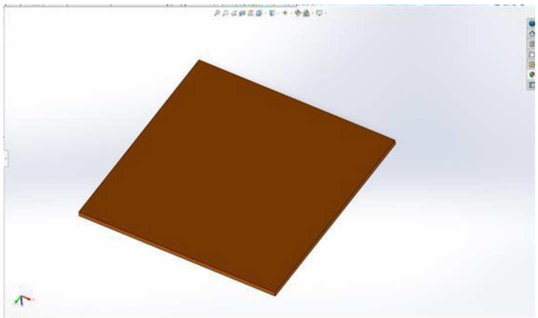

Fig 5: CAD model of glass

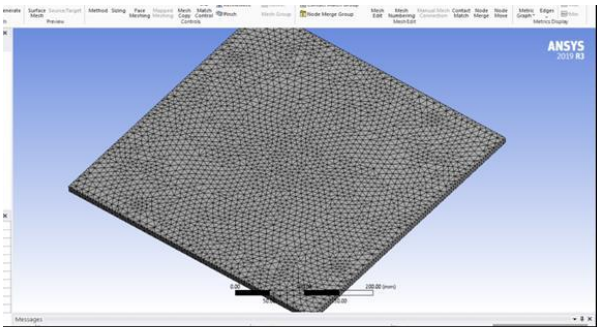

Fig 6: Mesh Generation

Transient Analysis Setup

With the mesh generation completed, we proceeded to set up a transient analysis using ANSYS Thermal Transient to simulate the dynamic evolution of temperature distribution within the glass plate over a specified time interval. The transient analysis spanned a duration of 10 seconds, allowing us to capture the temporal variation of temperature under transient heating conditions. The simulation setup incorporated realistic material properties, boundary conditions, and heat sources to emulate real-world operating conditions accurately.

In configuring the boundary conditions for the FEM simulation, careful consideration was given to replicating the physical constraints encountered in practical scenarios. At the inlet face of the glass plate, a heat flux of 0.333 W/mm^2 was applied to simulate the effect of strip heaters, ensuring a realistic representation of the heating mechanism. To emulate adiabatic conditions, three faces of the glass plate were designated as perfectly insulated, preventing heat transfer across these boundaries. Additionally, convective heat transfer coefficients of 25W/m^2 and 15W/m^2 were prescribed at the outside and inside surfaces of the glass plate, respectively, to account for heat dissipation through convection.Upon completion of the FEM simulation, we meticulously analysed the temperature distribution within the glass plate to assess the accuracy and reliability of our numerical model. Notably, after 10 time steps of 1 second each, the temperature at the farthest point from the source of heating reached 10.924°C, closely mirroring the results obtained from the MATLAB simulation. This remarkable agreement between simulation results served to validate the fidelity and predictive capability of our numerical modelling approach, reaffirming the consistency and reliability of our findings across diverse computational platforms.

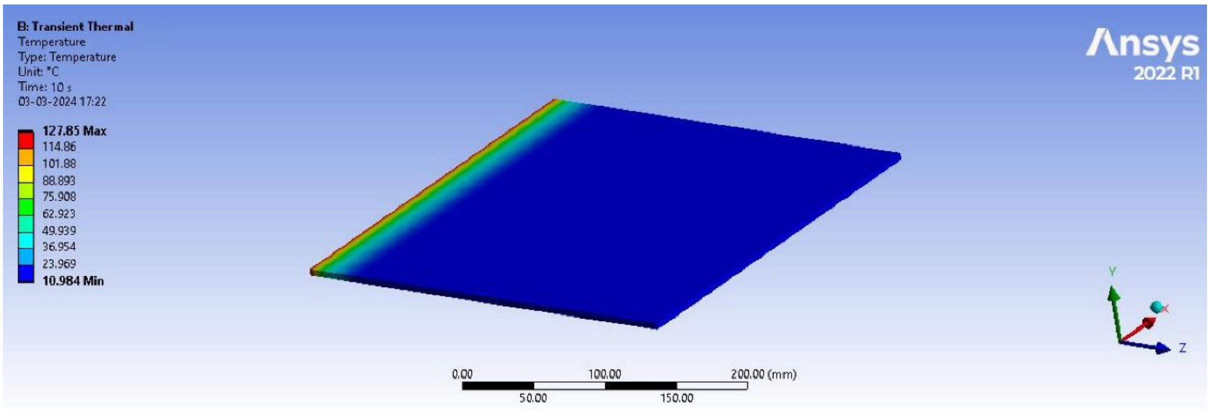

Fig 7: FEM result of spatial variation of temperature across Glass Plate

Prototype Development

The first step in constructing the working prototype involved the careful preparation of the glass plate. Utilizing precision cutting techniques, we fabricated a 30 cm x 30 cm glass plate, ensuring uniformity and structural integrity. Additionally, three holes were strategically drilled at the top of the glass plate to facilitate the attachment of the heating elements. To provide structural support and stability to the glass plate, we engineered a wooden stand with meticulous attention to detail. The wooden stand featured a centrally located groove designed to securely accommodate the glass plate in a vertical orientation, ensuring optimal visibility and accessibility during operation.

Heating Element Integration

Central to the functionality of the prototype was the integration of the heating element. We meticulously connected the heating rod to electrical wires, ensuring reliable power transmission and thermal performance. Additionally, a relay was strategically attached to one of the wires of the main power supply, enabling precise control and modulation of heat output. To enable real-time monitoring and control of temperature parameters, we integrated advanced sensors into the prototype. Specifically, an LM35 temperature sensor and a DHT11 temperature and humidity sensor were interfaced with an Arduino microcontroller. This integration facilitated accurate measurement of temperature variations within the glass plate, empowering dynamic adjustments and optimizations.

Central to the operational functionality of the prototype was the seamless integration of the Arduino microcontroller and relay. Through meticulous wiring and configuration, we established a robust communication interface between the Arduino and relay, enabling precise control over the activation and deactivation of the heating element based on real-time temperature data.

Code Development and Implementation

The culmination of the prototype development process involved the meticulous crafting of code to orchestrate the various components and functionalities seamlessly. Leveraging the versatile programming capabilities of the Arduino platform, we devised a comprehensive codebase encompassing temperature sensing, data processing, decision-making logic, and relay control. This code was meticulously refined and optimized to ensure reliable and efficient operation under diverse operating conditions.

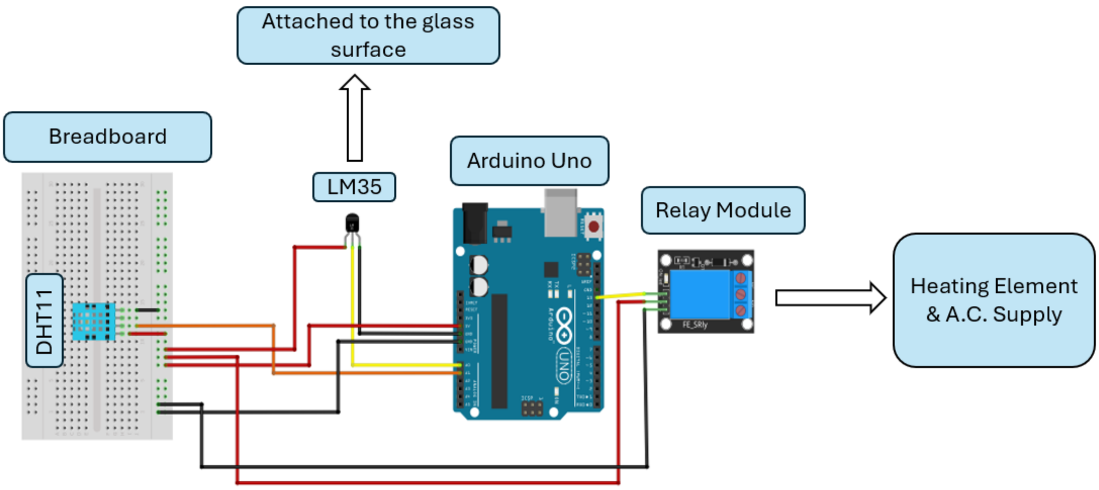

Fig 8: Electronic Circuit Diagram

In our pursuit of developing a robust and efficient automatic defogger system, meticulous attention was devoted to the design and configuration of the electronic circuitry. The electronic circuit served as the cornerstone of the prototype, facilitating seamless integration and communication between various components, including sensors, relays, and the Arduino microcontroller.

Central to the functionality of the electronic circuit were the LM35 and DHT11 sensors, which played a pivotal role in real-time temperature monitoring and data acquisition. These sensors were strategically connected to the analog pins A0 and A1 of the Arduino, respectively, to enable continuous voltage signal transmission and accurate temperature measurement.

Complementing the sensor array was the relay module, which served as the primary interface for controlling the heating element. The relay module operated on digital signals, utilizing the HIGH and LOW logic levels to toggle the heating element between ON and OFF states. To facilitate seamless integration with the Arduino, the relay module was connected to a digital pin, enabling precise control over the heating process. A critical aspect of the electronic circuitry was the provision of a stable power supply to all components. The VCC pins of the sensors and relay module were connected to a 5V power source derived from the Arduino, ensuring consistent and reliable operation. Additionally, the relay module was interfaced with both the heating element and the AC power supply, enabling efficient modulation of heat output. To streamline the interconnection of multiple sensors and components, a breadboard served as a versatile and effective means of circuit prototyping.

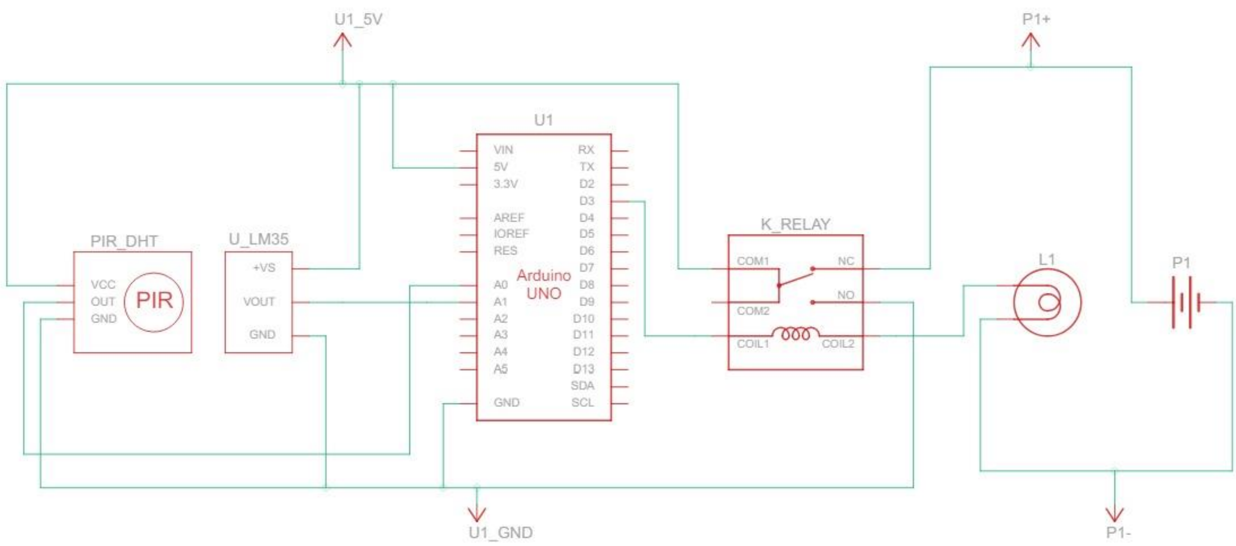

Fig 9: Electronic circuit connection diagram

This entire system is programmed in such a way (**code provided in appendix**) that the relay is switched ON once the temperature of glass is cooled below the DPT of surrounding air and is then switched OFF once the glass temperature exceeds the DPT. The DPT is calculated as :

D.P.T = $T_{air} - (100 - \phi_{air})/5$

The temperatures of glass and air and air humidity are measured in real time while the glass was kept in the cold storage to simulate foggy conditions.

Fig 10: 1.Working of wiper 2. Integration of all components 3. Working of heater

Image Classification for Defogger Activation using Transfer Learning

In automotive safety, visibility through windows is paramount, especially during adverse weather conditions such as foggy environments. Fogged windows obstruct the driver's view, posing significant risks on the road. To address this challenge, we present a novel approach leveraging image classification and transfer learning to automate the activation of defogger systems in vehicles. Maintaining clear visibility through vehicle windows is essential for safe driving, particularly in foggy or misty conditions. Traditional defogger systems are manually controlled or operate based on predefined settings, often leading to suboptimal performance. By integrating computer vision technologies with vehicle systems, we aim to enhance driver safety by automatically activating defoggers when visibility is compromised.

The data was curated by extracting frames from the video samples collected during experimentation. The data was labelled and then organized in class-named folders and was then retrieved with :

```
train_dir = os.path.join(PATH, 'dataset')
validation_dir = os.path.join(PATH, 'dataset')

BATCH_SIZE = 32
IMG_SIZE = (478, 848)

train_dataset = tf.keras.utils.image_dataset_from_directory(
    train_dir,
    validation_split=0.4,  # 40% of the dataset will be used for validation
    subset="training",  # Use the subset for training
    shuffle=True,
    seed=123,  # Provide a seed for consistent splitting
    batch_size=BATCH_SIZE,
    image_size=IMG_SIZE
)
```

Utilizing transfer learning, we employed Google's MobileNet pre-trained model to extract relevant features from the captured images. By leveraging the learned representations from MobileNet, we sought to identify visual cues indicative of foggy conditions.

```
base_model = tf.keras.applications.MobileNetV2(input_shape=IMG_SHAPE,
                                               include_top=False,
                                               weights='imagenet')
```

Model Architecture

Building upon the MobileNet feature extractor, we designed a binary classification model with a sigmoid activation function. This model was trained to predict whether fog is present on the glass screen setup , thereby facilitating automatic activation of the defogger system.

```
prediction_layer = tf.keras.layers.Dense(1, activation='sigmoid')
```

Training and Experimentation

The model was trained using binary cross-entropy loss and optimized with stochastic gradient descent (SGD), employing a batch size of 32. Training was conducted over 10 epochs, with validation monitoring to prevent overfitting. We evaluated the performance of our model on a separate testing set, measuring classification accuracy as the primary metric. Additionally, we assessed cross entropy on our dataset to gauge the model's effectiveness in detecting foggy conditions.

```
base_learning_rate = 0.0001
model.compile(
    optimizer=tf.keras.optimizers.Adam(learning_rate=base_learning_rate),
    loss=tf.keras.losses.BinaryCrossentropy(),
    metrics=[tf.keras.metrics.BinaryAccuracy(threshold=0.5, name='accuracy')]
)
```

Results

Our model demonstrated a high classification accuracy of 97%, showcasing its potential for accurately identifying fog on vehicle windows. Cross entropy measurements further validate the model's performance across both foggy and clear conditions.

The successful deployment of our image classification model for defogger activation underscores its relevance in enhancing driver safety and comfort. Further refinement and real-world testing are warranted to ensure robustness and reliability across diverse driving scenarios.

In conclusion, our approach utilizing transfer learning and deep learning techniques offers a promising solution for automating the activation of defogger systems in vehicles. By integrating computer vision capabilities, we can proactively address visibility challenges caused by foggy conditions, thereby mitigating risks on the road and enhancing the driving experience.

Fig 11: Predicting validation set's labels with fitted model

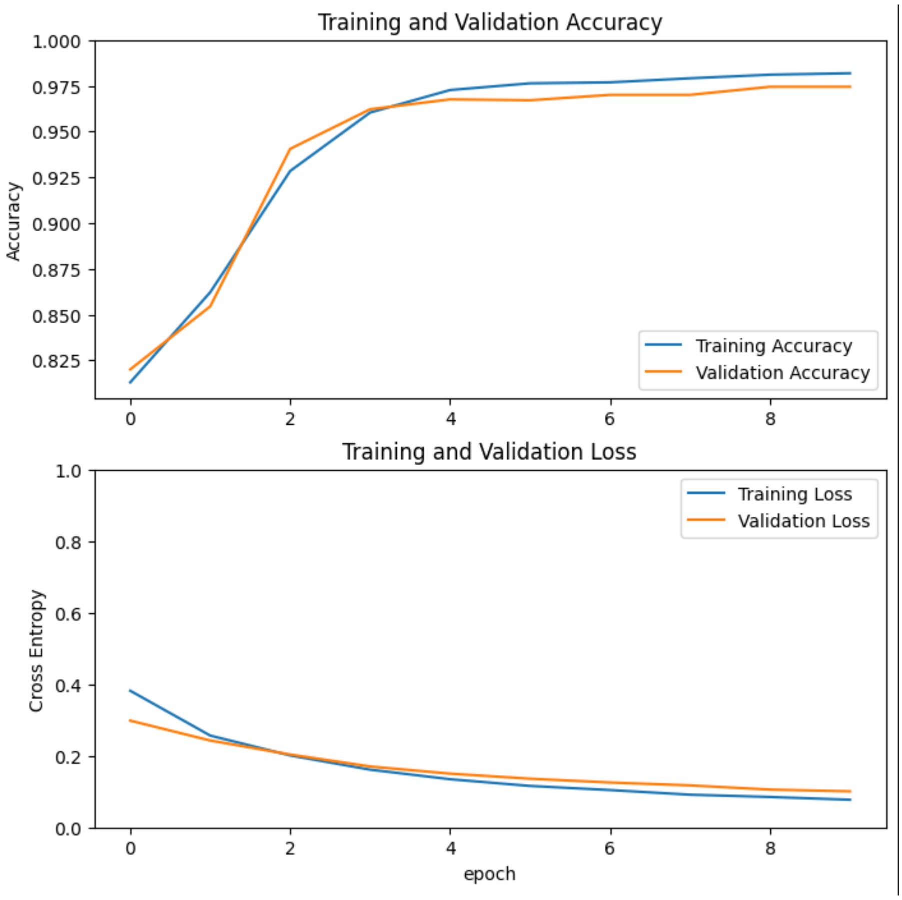

Fig 12 & 13: Model accuracy and cross entropy calculation for fitted model.

Experimental Results and Conclusions

Upon testing the prototype under controlled conditions, we observed significant improvements in fog removal efficiency compared to natural conditions. With the defogger system activated, the temperature of the glass increased from 3.14°C to 18.8°C within 69 seconds (which was recorded by the LM35 sensor installed at 4/5th of the height from the top), reaching the dew point temperature (DPT). Subsequently, the system deactivated, and the temperature continued to rise gradually to 21.23°C by the 96th second.

In contrast, under natural conditions without the defogger system, the temperature increased from 4.36°C to 20.33°C over 346 seconds. This comparison reveals that our prototype achieved fog removal approximately five times faster than natural conditions, highlighting its effectiveness in improving visibility and safety.

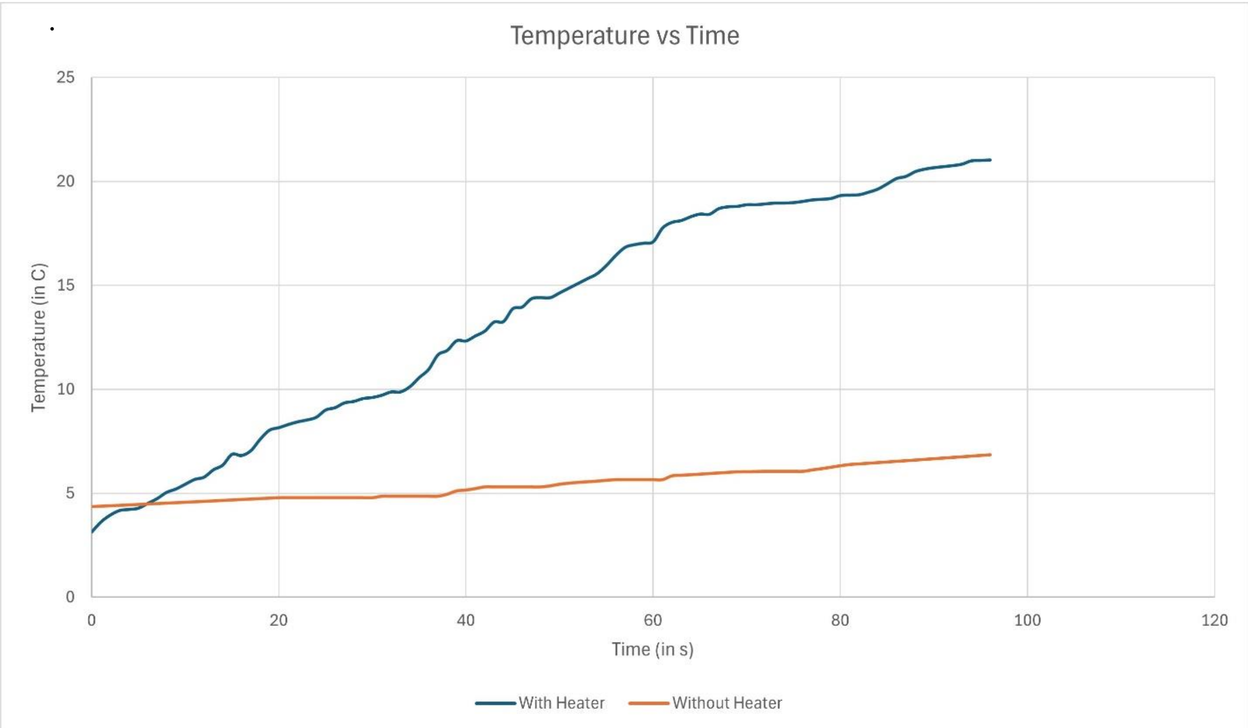

Fig 14 : Experimental Result of Temperature increase with and without conducting heating strip.

Moving forward, our focus will be on further refining and optimizing the prototype design to enhance performance and versatility. Additionally, we aim to explore potential applications and deployment scenarios to maximize the impact of our innovative defogger system in real-world settings like we can install the heating element in the wiper of the windshield and run it in the synchronized motion of the outer wiper to maximize the energy saving and faster defogging.

Acknowledgement

We extend our heartfelt gratitude to our supervisor Prof. Ajit Kumar Dubey for his unwavering support and guidance throughout the completion of this project. His expertise and encouragement have been instrumental in shaping our ideas and navigating the challenges encountered during the course of our research. Additionally, we are deeply thankful to Prof. Arup Kumar Das for his invaluable feedback, which played a significant role in refining our design and approach, ultimately enhancing the quality of our work. We also acknowledge Prof. Sudhakar Subudhi for generously providing us with access to the necessary facilities and resources, without which this project would not have been possible. Our sincere appreciation also goes to the dedicated staff of the Mechanical and Industrial Engineering Department at IIT Roorkee for their assistance and cooperation throughout this endeavour. Lastly, we express our gratitude to the Tinkering Lab for their support and assistance in the development of our project, which has contributed to its successful completion.

Appendix

CODE FOR HEATING THE GLASS NORMALLY

```
#include "dht.h" // DHT11 Arduino Library
#include <ErriezLM35.h> // This library changes ADC to 1.1V internal reference voltage #define
LM35_PIN  A0 // Connect LM35 data pin to Arduino DIGITAL pin
LM35 lm35 = LM35(LM35_PIN);
#define dht_apin A1 // Analog Pin sensor is connected to Arduino
int relay = 13; // Plug the relay into Digital Pin 13
dht DHT;
float dpt;
void setup() {
  Serial.begin(9600);
  delay(500);//Delay to let system boot
  pinMode(relay, LOW); .// Relay is at OFF position at start
}
void loop() {
    DHT.read11(dht_apin); // Reading air temperature and humidity from DHT11 sensor
    Serial.print("Current humidity = ");
    Serial.print(DHT.humidity);
    Serial.print("%  ");
    Serial.print("Temperature of air = ");
    Serial.print(DHT.temperature);
    Serial.println("C  ");
    delay(1000);//Wait 5 seconds before accessing sensor again.

    dpt = DHT.temperature - ((100-DHT.humidity)/5); // Dew-Point Temperature
    Serial.print("DPT :");
    Serial.print(dpt);
    uint16_t lm35_temp = lm35.readTemperature(); // Reading glass temperature from LM35
    Serial.print(F("Glass Temperature: "));
    Serial.print(lm35_temp);
    if (lm35_temp < dpt)
      digitalWrite(relay, HIGH); // Turn the relay on
    else
      digitalWrite(relay, LOW); // Turn the relay off
    Serial.print(" Glass Temperature = ");
    Serial.print(lm35temp);
    Serial.println(" °C");
    DHT.read11(dht11Pin);
    Serial.print(" Air humidity = ");
    Serial.print(DHT.humidity);
    Serial.print("%  ");
    Serial.print(" Air temperature = ");
    Serial.print(DHT.temperature);
    Serial.print(" C");
    Serial.print(" DPT = ");
    Serial.print(dpt)
    Serial.print(" C");
    delay(1000); // Delay of 1 sec }
```

Servo Motor Code For Rotation of Wiper-

```
// Include the Servo library
#include <Servo.h>
// Declare the Servo pin
int servoPin = 3;
// Create a servo object
Servo Servo1;
void setup() {
  // We need to attach the servo to the used pin number
  Servo1.attach(servoPin);
```

```
void loop(){
  // Make servo go to 0 degrees
  Servo1.write(0);
  delay(1000);
  // Make servo go to 90 degrees
  Servo1.write(60);
  delay(1000);
}
```

References

1. https://www.tensorflow.org/
2. https://patents.google.com/patent/CN205193381U/en
3. https://www.calculator.net/dew-point-calculator.html
4. Heat and Mass Transfer by Incropera