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Automatic Windshield Wiper Control System using MATLAB

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Abstract: This paper discusses the design and simulation of an rain sensor which automatically senses rainfall intensity and controls the speed of the windshield wiper using a PID controller. The system automatically detects intensity of rainfall by means of a simulated sensor which then controls the speed of the wiper motor according to the rain level inputs ensuring quick adaptation to environmental changes. The closed-loop control system is implemented in simulink and the PID controller enhances the precision, ensures system's stability, and dynamically adjusts speed of the wiper motor resulting in continuous and efficient wiping under fluctuating rain levels.
Keywords: Rain sensor, windshield wiper, PID controller, Simulink, closed-loop control systems.

I. INTRODUCTION

The most commonly used means of transportation in urban areas are cars, but they contribute significantly to road accidents, often because of the carelessness and distractions that reduce the concentration of the driver. Distracting activities while driving are common, and they can even result in causing driving errors. Driver distraction is an important cause of crashes, and the number of accidents caused by distraction can be slightly reduced by eliminating the need for drivers to adjust wiper speed. Most of the windshield wipers on vehicles (cars) are manually operated, and the traditional wiper system requires the driver's constant attention in adjusting the wiper speed using a manual switch. And sometimes dust particles floating in the air are covered in the windscreen during a moving vehicle, which could be another cause of an accident. The manual adjustment of the wiper and windscreen washing spray distracts the driver's attention, which may be a direct cause of accidents. The design and simulation of an automatic rain-sensing wiper control system were carried out using MATLAB Simulink. The primary input device used in this project is the rain sensor. Based on the real-time input from the rain sensor , the PID Controller regulates the speed of the wiper motor. Different speeds were indicated for different levels of rain fall where according to the control logic. The DC motor receives input from the controller and rotates to move the wiper blades.

According to the United States Department of Transportation, car accident cases have increased worldwide due to distraction caused by various means, which also includes the car wiping system [1]. The evolution of windshield wiper systems began with Mary Anderson, who was the first one to invent the manual windshield wiper in 1905 [3]. Her wiper system is called a "window cleaner," which is designed with a rubber blade, metal arm, and a lever. This window cleaner system requires manual work by drivers to operate the lever, which in turn makes the blade move back and forth across the windshield. This was considered to be a major improvement in the process of cleaning car windshields as compared to the traditional method of cleaning, which requires cloths or brushes to clean them while driving. Although this was a significant improvement over the practice of cleaning windshields with cloth or brushes, it still requires manual effort and thus puts people at safety risk. To address this, Dr. Ormond Wall developed a semi-automatic wiper system that uses an electric motor at the top center of the windshield. It was developed in 1917. This motor enabled a semicircular wiping motion. However, it still required the driver to manually activate the system, continuing the issue of distraction (Kulkarni & Holalad , 2012).

Hideki sasaki invented an automated wiper system by using an optical rain sensor. This wiper follows the principle of total internal reflection. This sensor detects the raindrops by analysing how light refracts through the windshield. This system is effective but is expensive and sensitive to interference. Pallavi (2016) and Dharmadhikari et al. (2014) introduced a system that uses piezoelectric materials to generate energy. The energy is generated when the raindrops strike the surface. The energy generated is then stored in a capacitor until sufficient voltage is reached to activate the wiper motor. This system is prone to false triggering.Varshitha et al. (2018) combined impedance and piezoelectric sensors with a microprocessor. This arrangement allowed the system to detect rainfall and its intensity more accurately and adjust wiper speed. This approach may give false signals.

Ashik and Basavaraju (2014) used a capacitive proximity sensor to detect rainfall. This system is partially effective but is sensitive to electrical fields and uses expensive electronic components.

Kulkarni and Holalad (2012) used 8051 microcontroller and a cup sensor. This model works in a way which it collects the rainwater in a tray, and it flows into a cup with various levels. As the rainwater level rises, signals are sent to the 8051 microcontroller. This microcontroller controllers the wiper speed based on the predefined stages. This cup sensor is vulnerable to particle interference and does not have a long lifespan.

Mitra et al. (2017) and Minar & Tarique (2012) developed Bluetooth-operated wiper systems using Arduino, HC-05 Bluetooth modules, and servo motors. Wipers are activated using a Bluetooth signal from a mobile system. This technique even requires driver interaction and thus does not fully eliminate distractions.

Karande et al. (2019) created an automated wiper system using a rainfall detector, servo motor, LCD, and Arduino microcontroller. This system automatically detects rainfall and activates the wipers accordingly. It lacks the ability to adapt to varying rain intensity levels[3],[5],[7] .

From manual to semi-automatic mechanisms to sensor-based systems, it is now evident that technology has been developed over time to automate windshield systems. Innovations have reduced drivers need for manual intervention. Many systems still have limitations such as high cost, short life span, false triggering, or lack of adaptability to varying rain intensities, but using a well-tuned PID controller or advanced sensor fusion could provide an effective alternative for modern vehicles.

To overcome this issue, the automatic rain-sensing wiper systems can be used. It adjusts speed based on rain intensity, reduces the driver's workload, and enhances road safety, minimizing the risk of accidents. This paper gives a clear view of how the design and simulation of an automatic wiper control system are done using Simulink, with a particular focus on the PID controller. The simulated rain sensor detects rain intensity, and the PID controller adjusts the motor speed according to the weather conditions. The closed-loop feedback system ensures accuracy, system stability, and faster response. This system was developed to minimize driving distractions in order to allow drivers to focus on their primary task of driving.

II. COMPONENTS USED

The design and simulation of an automatic rain-sensing wiper control system were carried out using MATLAB Simulink. It involves five main components, namely, a simulated rain sensor, a PID controller, a wiper motor system, a MATLAB function block, and rain intensity.

The rain sensor is used to signal by analysing the moisture level of the raindrops falling on the windshield and sends this signal to a control unit. This control unit interprets the input signal and determines the appropriate response. A PID controller is used to ensure smooth operation by controlling the speed of the motor and also it plays a main role in maintaining the system precision. The wiper motor used here is a DC motor.

It is used to drive the wiper. These components were implemented using MATLAB Simulink, and multiple test scenarios were simulated to evaluate system performance under different environmental conditions [1].

A. Rain Sensor

The primary input device used in this project is the rain sensor which represents the intensity of the rainfall. The rain sensor module is simulated to real world rainfall by generating input signals corresponding to the varying rain intensities. This is done by using Random Number block that generates varying values that resembles the randomness of real-life incidents like weather conditions. It generates random variables by following probability distributions, Gaussian by default. As it produces random fluctuations in input, which in turn represents a range of realistic conditions. A saturation block is added to further process the random number block's value this saturation block is to restrict the unrealistic values produced by random number block and ensures that the values are between the predefined range. This combination of random number block and saturation block is used to get a realistic rainfall intensity with randomness and without exceeding to unrealistic values [14],[2].

B. PID Controller

Based on the real-time input from the rain sensor used the PID Controller regulates the speed of the wiper motor. It makes the wiper motor to accelerates or decelerates smoothly depending on the observed rainfall amount and reduces the lag or lead therefore enhancing the system response.

This also provides closed-loop feedback, ensuring precise tracking of the rainfall. It acts as the brain behind motor regulation which takes continuous input from the control unit and calculates how much the wiper motor speed should change in order to match the environmental conditions, this helps in maintaining the system reliability and driver comfort.

Implementing this into the Simulink model, it continuously processes the feedback and fine-tunes the motor output, it ensures that the motor responds corresponding to rain intensity, smoothing the rapid changes, avoiding excessive motion. In this context, the controller bridges the gap in between real sensor data and the mechanical motion.

The PID Controller converts the environmental inputs into motor control signals, which ensures a seamless transition in wiper speed as the rainfall increases or decreases. It also provides a structured approach to control the wiper motor by adjusting three key variables: proportional response to error, accumulated past errors and also the future ones. This combination ensures that the wiper responds naturally under real-time weather changes. Functioning as a continuous feedback loop, the PID controller monitors the difference between expected and the original motor performance and responds to minimize the error. The controller plays a main role in maintaining the system precision. Without the PID algorithm, the motor may not adjust accurately to varying rain levels and the errors cannot be corrected. In this simulation, it effectively manages fluctuations in the speed and delivers a highly responsive wiper system [5], [3].

C. DC Wiper Motor

The DC wiper motor is responsible for driving the wiper arms based on the control signals which translates the electrical output from the PID into mechanical movements allowing the wipers to sweep at varying speeds, the actuator i.e the DC motor receives input from the controller and rotates to move the wiper blades. Similarly, in the simulated model, the DC motor plays a crucial role by transforming command signal to rotational motion.

This motion drives the wiper arms and the speed changes according the to the intensity of the rainfall which makes it essential in maintaining clear vision, it replicates the action of real windshield wipers and the speed is regulated by the controller, ensuring the motor acceleration to rainfall intensity [4], [6].

The Transfer Function Block in Simulink is used to represent the physical response of the DC motor which drives the wiper. In this simulation, a first order transfer function is used.

$$G(s) = \frac{1}{s + 10}$$

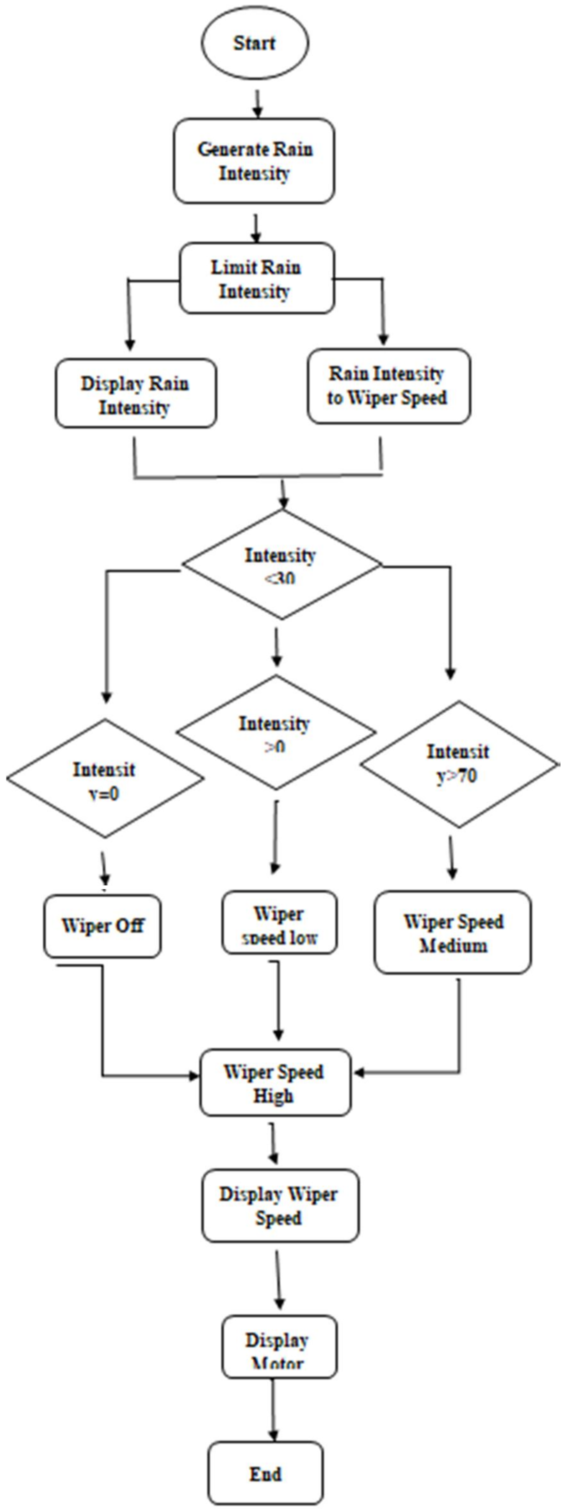
This explains a system with no steady-state gain represented by numerator as 1 and a time constant of 0.1 seconds which represents that this system can respond quickly but not instantly. If there is any sudden changes in the wiper speed this block will smooth it. This ensures the increase and decrease of motor by working with PID controller. This represents the real-life motion of wipers.

D. MATLAB Function Block

The control logic acts as an intermediator between translating input from the rain sensor into discrete control signals for controlling the wiper speed accordingly. This can be obtained by implementing a MATLAB Function Block in Simulink. which allows user to write their custom algorithms using MATLAB code. This code helps to analyse the performance and allows for decision making between the sensor used here and the PID controller.

The function block takes rain intensity as input and classifies it into wiper speed levels:
For 0: No rain is detected. Wiper is in Off condition.
For 1: Light rainfall (rain intensity < 30). Wiper is at Low speed.
For 2: Moderate rainfall ($30 \leq$ rain intensity < 70).
Wiper is operated at Medium speed.
For 3 (HIGH): Heavy rainfall (rain intensity ≥ 70). Wiper is at High speed.
By using this logic wiper speed is changed in levels based on the intensity of rain detected. This logic enables the system to adapt for the varying rain intensity in real time. This logic empowers energy efficiency by activating the wiper when it is needed. It facilitates real-time adaption and accuracy [5].

III. FLOW CHART



IV. SIMULATION

A. Block diagram

An automatic windshield wiper control system is implemented in a Simulink environment. The intensity of the rain is detected by a rain sensor . Based on the intensity of the rainfall the speed of the windshield wiper is varied. In the beginning a rain sensor block is attached at first. This block simulates the presence and variation of rain intensity. The output of rain-sensor block splits into two branches: one path leads to a scope while the other is served as an input for wiper logic control block. The scope of the block displays the real time rain intensity observation and the other block processes rain intensities and determine appropriate wiper speed. The wiper control logic block categorizes rain intensities to 3 levels such as light, moderate and heavy and determine the speed of wiper as slow, medium and fast. The output of the wiper logic control block is then served to s scope . This scope is used here to visualize the speed level. The scope is fed to the PID controller. The PID controller compares wiper speed and generate a control signal that drives a motor without any error. The control signal is sent to DC motor block, in which the dynamic behavior of actual wiper motor determined using a transfer function is obtained. Here,

$$G(s) = \frac{1}{s + 10}$$

is a transfer function. The motor output is then connected to another scope. The motor’s output, representing the actual speed of the wipers, is finally connected to another scope for monitoring. This closed loop system ensures that wiper adjusts its speed automatically to varying rain conditions, thereby enhancing driver visibility and safety.

B. Rain Sensor Configuration

The rain sensor in the simulation is approximated using random number generating function block. This replicates the fluctuation and unordered nature of rainfall. The Guassian-distributed signal is a normal distribution signal which is a bell shaped probability distribution. Due to this nature, the Gaussian-distributed signal produced by this block is ideal for modeling natural processes. The distribution's mean value is set to 50 and its variance is set to 900 in to represent different variants of rain intensities very accurately. These factors ensures a realistic range of values corresponding to different levels which is mild, moderate, and heavy rainfall conditions. The large range of intensity values are made possible by the setting variance to a high value. This results in capturing the dynamic and varying character of precipitation in the real world. The data generation is consistent which provides a steady stream of input to any systems or models enabling accurate analysis, testing, and validation of rain-sensitive mechanisms.

C. Rain Intensity Saturation Block

The Saturation blocks plays a crucial role which keeps the simulated rain signal within specific bounds .The signal which is the input signal here is constrained between a lower limit of 0 and an upper limit of 100. Values below 0 are set to 0, and values above 100 are set to 100. This means that any values produced by the previous random number block that fall outside of the range between 0 and 100 are clipped. This constraint is necessary because in real-world situations, rain intensity often falls within a measurable range and rain intensities cannot be negative.

D. PID Controller setup

The PID controller is set up to function in the continuous-time domain and the integral and derivative components set to zero and only the proportional component is active. In particular, the proportional gain (P) is set to 1, which means that the controller reacts to the present error immediately without taking into account the total of previous errors (integral) or forecasting errors in the future using the rate of change (derivative).The PID controller modifies the DC motor speed by processing the error signal which results in regulating the wiper mechanism appropriately.

E. Wiper Control Logic (MATLAB Function)

Wiper speed controller mechanism were based on different rain intensities is defined using a MATLAB Function Block. Diffrerent speeds were indicated for different levels of rain fall where according to the control logic they are categorized as,

Speed 0 indicating no rain,
Speed 1 indicating light rain,
Speed 2 indicating moderate rain, and
Speed 3 indicating heavy rain.

This reasoning guarantees that the wiper speed is suitable for the amount of rainfall.

```
function speed = wiper_control(rain)
    if rain == 0
        speed = 0;   % Wiper OFF
    elseif rain < 30
        speed = 1;   % Wiper Low Speed
    elseif rain < 70
        speed = 2;   % Wiper Medium Speed
    else
        speed = 3;   % Wiper High Speed
    end
end
```

Conditional statements like if, else if were used in control logic in order to classify the rain intensities and to set wiper speed accordingly.

F. DC Motor Transfer Function

The transfer function which is $\frac{1}{s+10}$ is used in Simulink Transfer function block. It is modelled in Simulink as a basic DC motor. The numerator coefficient is set to [1] and denominator coefficient is set to [1 10]. It is used in such a way to replicate the dynamic response of the motor to the PID controller's control signal. The characteristic equation in the Transfer function illustrates that there is a single pole and it is a first order system .The parameter tuning is set to 'Auto' so that Simulink can identify the necessary parameters for code generation or simulation.The absolute tolerance is then also set to 'Auto' and there is no specific name .This is kept in a way that the setup can be used frequently to examine or regulate how DC motor will respond to variations in input voltage

G. Output Display: Rain Intensity

This display presents the simulated rain intensity values which have been produced previously by the Gaussian distribution which changes over time. It is done to test the control logic under various environmental conditions and rainfall scenarios.

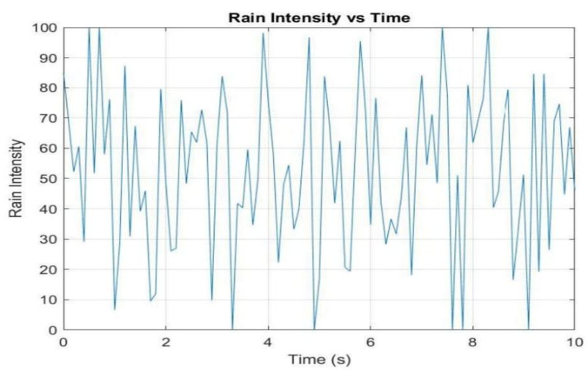


Fig.1. Rain Intensity vs Time

The "Rain Intensity vs Time" graph explains how the intensity of a given rain intensity varies over time. Time (in seconds) is shown in x-axis, and the corresponding rain intensity, is displayed in the y-axis. This graph is used to understand the wiper control system performance to varying rain conditions.

1.At t = 1 second, Rain Intensity ≈ 90

That means it's going to rain a lot. To get clear vision to the road, the wiper control logic is settled to wiper to its maximum speed.

2. At t = 2.5 seconds, Rain Intensity ≈ 50

That indicates moderate amount of rain. In order to get clear visibility, the system is settled to lower the wiper to a medium speed.

3. At t = 4 seconds, Rain Intensity ≈ 10

It indicates raining very lightly. The windshield is primarily clear, the wiper system may cause the wiper to stop for a period of time or slow down.

4. At t = 6.5 seconds Rain Intensity ≈ 80
This indicates a return to high intense rain level, which causes the system to accelerate the wipers speed to manage the increased rain intensity.
5. At t = 9 seconds Rain Intensity ≈ 35
The wiper system keeps the wipers running at a low speed because of light rainfall.
This graph clearly shows the amount of rain intensity varies over a short period of time. The wiper system change the wiper speed corresponding to the rain intensity level. Here, the PID controller is used to makes sure the motor speed changes according to the change in desired speed.

H. Output Display: Wiper Speed
This display presents the wiper speed level output from the MATLAB Function block which depends only on the current rain input . The wiper speed levels starts from 0 and ends with 3 . It demonstrates how the system responds by adjusting wiper speed.

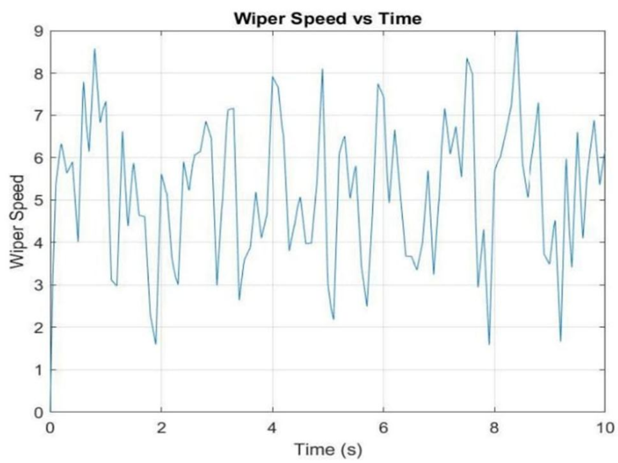


Fig.2 . Wiper speed vs Time

The "Wiper speed vs Time" graph explains how the speed of the wiper fluctuates over time .Here , the time in seconds is shown in x-axis, and the corresponding speed of the wiper system , is displayed in the y-axis. This graph is used to understand the performance of the wiper control system to varying rain conditions.
1. At t = 1 second, The wiper Speed ≈ 7
This shows that the windshield wipers move at a high speed, especially responding to heavy rain or a sudden increase in rain intensity.

2. At t = 5 seconds, Wiper Speed ≈ 5
This indicates that to adjust to a moderate rain level a medium speed is being used. This also promotes visibility and efficiency is being used. This also promotes the maximum clearing action visibility and efficiency.

3.At t = 8 seconds, Wiper Speed ≈ 9
This is the highest wiper speed in the graph .This indicates that high rain which is peak rain intensities require the maximum clearing action.

4. At t = 9.5 seconds, Wiper Speed ≈ 4
The wipers speed gradually slow down to a lower speed,as wiper speed significantly drops out from 9 to 4.5.This reflects reduced rain intensity or intermittent rain condition.
This graph shows how wiper speed varies continuously over eah time period. The rain intensities varies rapidly and also wiper speed is adjust accordingly to the rain intensities. Such behavior indicates the wiper system dynamically adjusts the motor speed to match to their rain intensities. The controller ensures smooth transitions of the wiper and hence it avoids jerks and keeps the windshield clear.

I. Output Display: DC Motor Response

The output display of the motor presents how the DC motor responds dynamically to the control signal from the PID controller. This confirms that the motor's mechanical system follows the desired wiper speed input effectively.

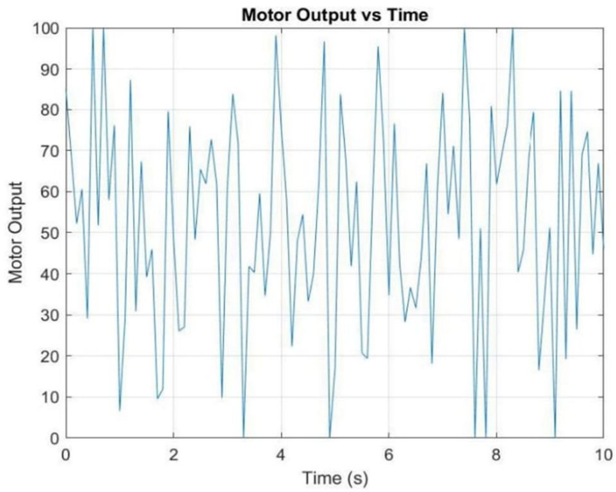


Fig.3. Motor Output vs Time

The graph "Motor Output vs Time" shows how the motor output fluctuates over a period of 10 seconds. The x-axis represents time (in seconds), while the y-axis shows the motor output level, which ranges from 0 to 100. This graph is useful for understanding the performance of motor to varying rain conditions .

1. At t = 1 second, Motor Output ≈ 95

This indicates that the motor is operating near its maximum output. The control system demands high power which means that the motor is responding to a higher load and it requires a fast action .

2. At t = 3 seconds, Motor Output ≈ 30

The output has reduced significantly to a low level from a maximum level, which indicates that the demand for faster action is reduced and a temporary light load is on the motor.

3. At t = 7 seconds, Motor Output ≈ 0

A brief pause or stop is indicated whenever the motor power falls to zero . This could be a response to an external signal or a deliberate control action.

4. At t = 9 seconds, Motor Output ≈ 60

The motor output is at a moderate level indicating that the motor is in a balanced operational state which is neither high nor low demand for action.

The graph clearly shows that the motor output varies rapidly over time . This indicates that the control system of the motor is adjusted automatically at each second inorder to respond to varying rain conditions .This could be important in applications like motor control systems or automatic devices responding to changing conditions. The immediate drop and spikes in output graph tells us that the adaption of the system to varied intensities is quick, but the motor also needs to manage stability so that wear and excessive oscillations of the motor can be avoided .

V. RESULTS AND DISCUSSION

The graphs obtained from the Simulink simulation offers insights to the performance of the system under different rain conditions. The output graphs obtained from the simulation highlights the dynamic nature of the designed control system which shows how the system adapts to variations to the external factors. The various levels of rain intensities is analysed to determine the system's behaviour . The model developed fulfills the functional requirements and also displays strong adaptability and robustness in replicating real-world operating conditions.

The rain intensity is modeled using a Gaussian-based signal that varies continuously over time thereby effectively replicating the unpredictable and irregular characteristics of natural rainfall. Using a Gaussian random process ensures that the rain intensity follows a non-linear, unpredictable path, thus providing a challenging input for the control system to manage. The simulated intensity spans upto a wider range from no rain to light drizzles, moderate rains and heavy rainfall. This wide variation seems to be a tremendous test for the wiper control system as the rain sensor's ability is to accurately detect and classify different rain levels. In addition to it, the transitions and fluctuations of the rain makes the simulation highly realistic and affirming that the rain detection and classification mechanisms handle dynamic and rapidly changing environmental inputs.

The wiper speed graph illustrates how the logic block uses the various rain intensities and changes them into different wiper motor speed levels for the wiper motor. when the rainfall is light, the system is set to operate at wiper speed of level 1, which is minimal , saves energy and lessens mechanical strain while wiping the windshield. As the rain intensifies and become heavier , the system is accelerated to operate at level 2 speed in moderate rainfall and during heavy rainfall the system is increased and operated at level 3 speed, which guarantees the driver constant and efficient visibility. This mechanism cleverly reduces the wiper speed to 0 during dry periods or when rainfall is stopped to prevent unnecessary movement of wiper. This adjustment of speeds to various showcases the accuracy and efficiency of the MATLAB Function Block, which classifies the rain intensity and assigns the correct wiper speed accordingly. This smooth and consistent transition between different speed levels shows the reliability of the classification and control logic, even when responding to abrupt changes in rain intensity.

The DC motor response graph provides a detailed representation of how the actuator responds to the speed command generated by the control logic. The motor output closely follows the desired wiper speeds,with a slight and expected delay introduced by the first-order transfer function incorporated into the system model. This delay simulates the natural inertia and mechanical lag that are inherent in real DC motors, thereby enhancing the fidelity of the simulation. Despite the presence of the lag, the performance of the motor remains stable, which is primarily due to the usage of a straightforward yet effective PID controller configuration into the block . With the proportional gain (P) set to 1, and both the integral (I) and derivative (D) gains set to 0, the controller will deliver required proportional responses without any of the added complexity of integral accumulation or derivative prediction.

The performance of the motor is quick and it is steady and not lag, because an efficient and a simple controller which is a PID controller is used . This controller often provides timely proportional responses without the extra hassle of integral accumulation or derivative prediction when the proportional gain (P) is set to 1 and the integral (I) and derivative (D) gains are both set to 0. This configuration readily minimizes oscillations and minimizes overshoot which in turn guarantees that the output of the motor system is well synchronized with fresh speed commands . The speed command is varied with different rain intensities . The actuation subsystem is correctly tuned which helps in better functioning irrespective of environmental conditions , as demonstrated by the responsive and stable motor behavior. This results in consistent and dependable wiper functionality under all rain scenarios.

VI. CONCLUSION

The design and simulation of an automatic windshield wiper system using MATLAB Simulink shows how important automation is for improving driver's safety and comfort. By adding a simulated rain sensor with a MATLAB function block combined with a PID-controlled DC motor, the system can automatically change the wiper speed based on the intensity of the rainfall, without manually controlling and adjusting the wiper speed. The use of a closed-loop feedback system, improved by a PID controller, makes sure the system runs in a stable manner without any major fluctuations developed in a way such that it doesn't need any manual controlling similar to what is needed in real driving conditions.

This project highlights how important role the PID controllers are for accurate speed control of wiper in vehicles. The PID controller helps the wipers to move smoothly between predefined speed levels, making sure that they work well without any delay or error which is very important when the weather changes quickly and could distract the driver. This simulation uses a Random Number block and a Saturation block to copy the random nature of real rainfall. A MATLAB Function Block sorts the speed of wiper based on rain intensity into different levels and chooses the right wiper speed, which makes the system operation more efficient.

Also, using a first-order transfer function to model the DC motor makes the motor behavior more efficient. This stops the wiper motor from transforming the speeds too quickly and keeps the change of operation smooth. This simulation model also builds a strong starting point for future upgrades, like using better and advanced sensors, by using any adaptive or fuzzy logic control, or putting the system into real cars with embedded hardware.In short, the project meets its goals by reducing the driver's workload, cutting down distractions, and making driving safer. The above mentioned simulation results confirm the design was a good choice and create a strong base for future research into smart and self-driving vehicle systems. Future work can focus on real hardware testing which makes the sensors more reliable. Fine-tuning the controller can also be done for better performance in different weather conditions.

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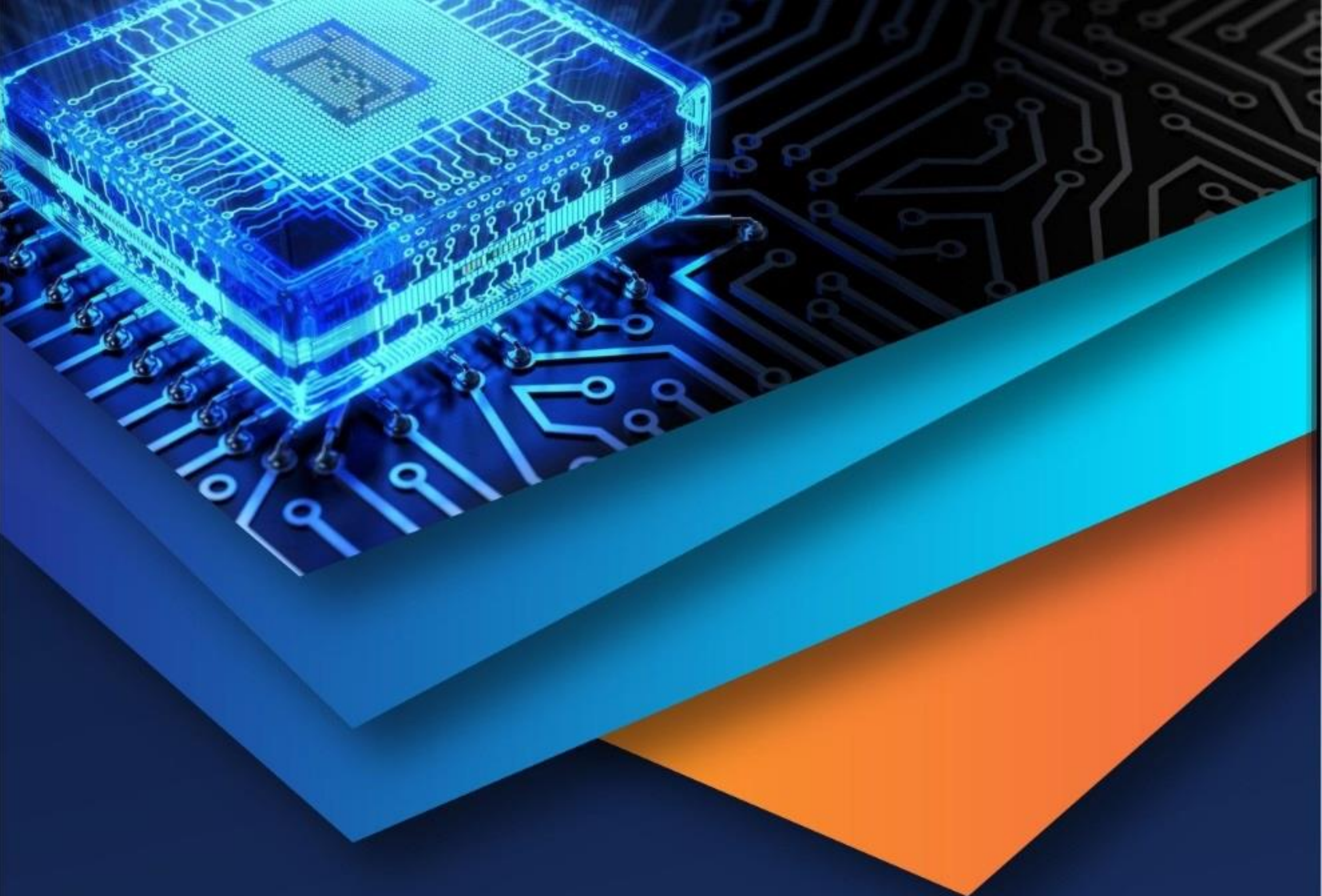

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