

Design and Implementation of an Automatic Rain Sensing Wiper System Using SEN0545 Sensor and Raspberry Pi Pico W

Rucha Kalebere¹, Ramesh Dhut^{2,*}, Shreya Kapne³, G.P. Tembhurnikar⁴

Abstract

This study presents the design and development of an intelligent, automatic rain-sensing wiper system designed to enhance vehicle safety. The system utilizes a SEN0545 capacitive rain sensor, integrated with internal signal processing, and a Raspberry Pi Pico W microcontroller as its central control unit. The proposed approach enables non-contact and corrosion-free rain detection, ensuring reliable performance under varying environmental conditions. Based on the detected rainfall intensity, the controller dynamically adjusts the wiping speed using a pulse-width modulation (PWM)-controlled DC gear motor. The adaptive mechanism improves visibility for drivers while minimizing distraction during harsh weather conditions. The system operates in real-time, delivering rapid responses and stable performance. Experimental results confirm that the proposed model offers accurate rain sensing, efficient control, and strong reliability. It may also be integrated into contemporary smart vehicles due to its small size and low power consumption. The developed system contributes to intelligent transportation by enhancing safety, automation, and user convenience. Overall, the proposed rain-sensing wiper system offers a cost-effective and efficient solution for advanced automotive applications. Overall, the proposed system requires minimal maintenance and can be adapted for various vehicle platforms, making it suitable for future smart automotive applications. It also ensures enhanced durability and operational efficiency.

Keywords: Automatic wiper system, SEN0545, Raspberry Pi Pico W, gear motor, capacitive rain sensor, embedded control, smart vehicle automation

INTRODUCTION

Road safety during adverse weather conditions remains a major concern in modern transportation systems [1–3]. Rainfall significantly reduces windshield visibility, increases driver workload, and elevates the risk of road accidents. Conventional windshield wiper systems rely on manual operation, requiring drivers to repeatedly switch the wipers on or off and adjust their speed according to the changing rainfall intensity. This continuous manual interaction diverts the driver's attention from the road and introduces reaction delays, especially during sudden rainfall events. As intelligent transportation systems evolve, the automation of safety-critical vehicle subsystems has become essential for improving driving safety, operational efficiency, and human-machine interactions.

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This study presents an automatic rain-sensing wiper system that integrates intelligent sensing, embedded control, and electromechanical actuation

into a unified automation platform. The system operates without driver intervention by continuously monitoring the environmental conditions and autonomously regulating the wiper motion. The proposed architecture comprises a SEN0545 capacitive rain sensor, Raspberry Pi Pico W microcontroller as the central control unit, motor driver interface circuit, DC gear motor-based actuation mechanism, and regulated power management system. Together, these components form an intelligent closed-loop control system capable of real-time decision making and adaptive mechanical control. Table 1 shows a comparison with the conventional system.

The working principle of the system is based on non-contact capacitive rain detection and an intelligent control logic. The SEN0545 sensor (Figure 1 and Tables 2 and 3) generates an electric field across its sensing surface, where rainfall causes dielectric variation and capacitance change. This change was converted into a voltage signal and transmitted to the Raspberry Pi Pico W controller (Figure 2 and Table 4) for real-time processing and rainfall classification. Based on the processed sensor input, the controller generates appropriate control commands for the motor driver circuit [4].

Table 1. Comparison with conventional system.

Parameter	Conventional system	Proposed system
Operation	Manual	Automatic
Sensor Type	Resistive Sensor	SEN0545 Sensor
Speed Control	Fixed	Adaptive
Reliability	Medium	High
Driver Effort	High	Low
Maintenance	More	Less
Response Time	Slow	Fast (100 ms)

Table 2. Specifications of SEN0545 sensor.

Parameter	Value
Sensor Type	Capacitive Rain Sensor
Operating Voltage	3.3–5 V
Communication Interface	UART
Detection Levels	4
Response Time	100 ms
Application	Rain Detection

Table 3. Specifications of SEN0545 sensor.

Component	Component pin	Raspberry Pi Pico W pin	Function
SEN0545 Rain Sensor	VCC	3.3 V (Pin 36)	Power supply
SEN0545 Rain Sensor	GND	GND (Pin 38)	Ground
SEN0545 Rain Sensor	TX	GP1 / UART0 RX (Pin 2)	Serial data output
SEN0545 Rain Sensor	RX	GP0 / UART0 TX (Pin 1)	Serial data input
L298N Motor Driver	IN1	GP14 (Pin 19)	Motor direction control
L298N Motor Driver	IN2	GP15 (Pin 20)	Motor direction control
L298N Motor Driver	ENA	GP13 (Pin 17)	PWM speed control
L298N Motor Driver	VCC	5 V (Pin 40)	Logic power supply
L298N Motor Driver	GND	GND (Pin 38)	Ground
Limit Switch 1	Signal	GP10 (Pin 14)	Park position feedback
Limit Switch 2	Signal	GP11 (Pin 15)	End position feedback

Table 4. Raspberry Pi Pico W specifications.

Parameter	Value
Controller	RP2040
Clock Speed	133 MHz
SRAM	264 KB
Flash Memory	2 MB
Wi-Fi Support	Yes
Operating Voltage	3.3 V

Source: [4]



Figure 1. SEN0545 capacitive rain sensor module used for non-contact digital rainfall detection.



Figure 2. Raspberry Pi Pico W microcontroller used as the central processing and control unit in the proposed system.

For mechanical actuation, a DC gear motor was used instead of a conventional wiper motor. The gear motor provides controlled speed reduction and torque amplification through a reduction gear box, enabling smooth motion, high torque output, and precise speed regulation. The Raspberry Pi Pico W regulates the gear motor using PWM and directional control signals, enabling adaptive wiping under light, moderate, and heavy rainfall conditions. The proposed system enhances driving safety by eliminating manual wiper operation, reducing driver distraction, improving sensing reliability, and supporting intelligent vehicle automation for smart mobility and future autonomous transportation systems [5, 6].

Related Work

Existing automatic wiper systems in the literature primarily use resistive rain sensors and basic threshold-based control methods. However, these systems suffer from corrosion, conductivity variations, and long-term reliability issues [1–3, 7]. Optical and infrared sensors improve detection accuracy but increase system complexity and cost. Recent studies have highlighted the importance of embedded intelligence and adaptive control; however, challenges related to sensing reliability, mechanical control stability, and system durability remain [8, 9]. The proposed system addresses these

challenges using capacitive sensing technology, intelligent control logic, and robust mechanical actuation using a gear motor.

System Architecture

The system architecture comprises a SEN0545 intelligent rain detection module, a Raspberry Pi Pico W-based embedded controller, signal interfacing stage, high-current motor driver circuit, DC gear motor actuation unit, regulated power management subsystem, and mechanically coupled wiper linkage with an integrated positional feedback network. The SEN0545 functions as a smart digital rain-sensing unit with embedded signal processing, internally interpreting the presence and intensity of rainfall and transmitting digitally classified rainfall states to the controller through a UART interface, ensuring reliable and noise-immune communication [5, 8].

The Raspberry Pi Pico W receives and decodes the serial data, executes real-time decision-making, and generates low-level control commands for the motor driver to control the robot. The motor driver converts these commands into high-power drive signals for the DC gear motor, which produces controlled mechanical motion through its reduction gearbox, thereby enabling precise speed regulation and stable electromechanical actuation. A closed-loop mechanical feedback subsystem using limit switches provides positional feedback to the controller, enabling deterministic motion control and accurate execution of a return-to-park routine after each wiping cycle, thereby ensuring precise alignment, repeatability, and long-term operational reliability [4–5].

WORKING PRINCIPLE

The proposed system is an automatic rain-sensing wiper system (Figure 3) that operates autonomously without requiring manual control. The SEN0545 rain sensor detects rain and identifies whether there is no rain, light rain, medium rain, or heavy rain. This information was sent digitally to the Raspberry Pi Pico W controller via serial communication. The controller reads these data and decides how the wiper should move. If the rain is light, the wiper moves slowly with time. If the rain was moderate, it moved at a normal speed, and if the rain was heavy, it moved continuously without delay. The controller sends signals to the motor driver, which supplies power to the gearmotor. The gear motor moves the wiper mechanism. Figure 4 shows the circuit diagram of the interfacing of the SEN0545 sensor, Raspberry Pi Pico W, motor driver, and DC gear motor.

When it stops raining, the controller completes one wiping cycle and then automatically moves the wiper to the parking position using limit switches. This makes the system fully automatic, safe, and reliable, and reduces driver effort and distraction [2, 3, 8].

SEN0545 is an intelligent digital rain detection module that operates using an internal sensing and signal-processing algorithm to identify rainfall conditions. Instead of relying on conductivity, resistance, or capacitive dielectric variation, the sensor performs an onboard environmental analysis and internally processes the detected signals to determine the presence and intensity of rain. The processed data were directly converted into digitally classified rainfall states rather than raw analog values.

These classified rain states (i.e., no rain, light rain, moderate rain, and heavy rain) were transmitted to the controller through a UART serial communication interface, ensuring stable, noise-immune, and reliable data transfer. Because SEN0545 does not depend on water conductivity or exposed electrodes, it is immune to corrosion, oxidation, salinity effects, and contamination issues commonly associated with resistive rain sensors. This design improves the long-term reliability, environmental robustness, and sensing accuracy, making it suitable for automotive and intelligent mobility applications [3, 8].

The Raspberry Pi Pico W, which is based on the RP2040 microcontroller, serves as the central processing unit of the system. It handles the sensor data acquisition, signal processing, control algorithm execution, and motor control signal generation. The controller provides a high processing speed, low

power consumption, and stable real-time performance. Digital filtering, threshold comparison, and decision logic are implemented within the controller to ensure accurate control [5, 9]. Table 5 shows the bill of materials and cost analysis.

Table 6 lists the specifications of the components. A DC gear motor was used instead of a conventional wiper motor to improve torque control and mechanical precision. The gear motor comprises a DC motor coupled to a reduction gearbox. The DC motor converts electrical energy into rotational motion, whereas the gearbox reduces the speed and increases the torque. This allows for smooth and controlled movement of the wiper mechanism, even under high mechanical loads. Gear reduction ensures stable speed regulation, improved positioning accuracy, and long-term mechanical reliability [1, 8].

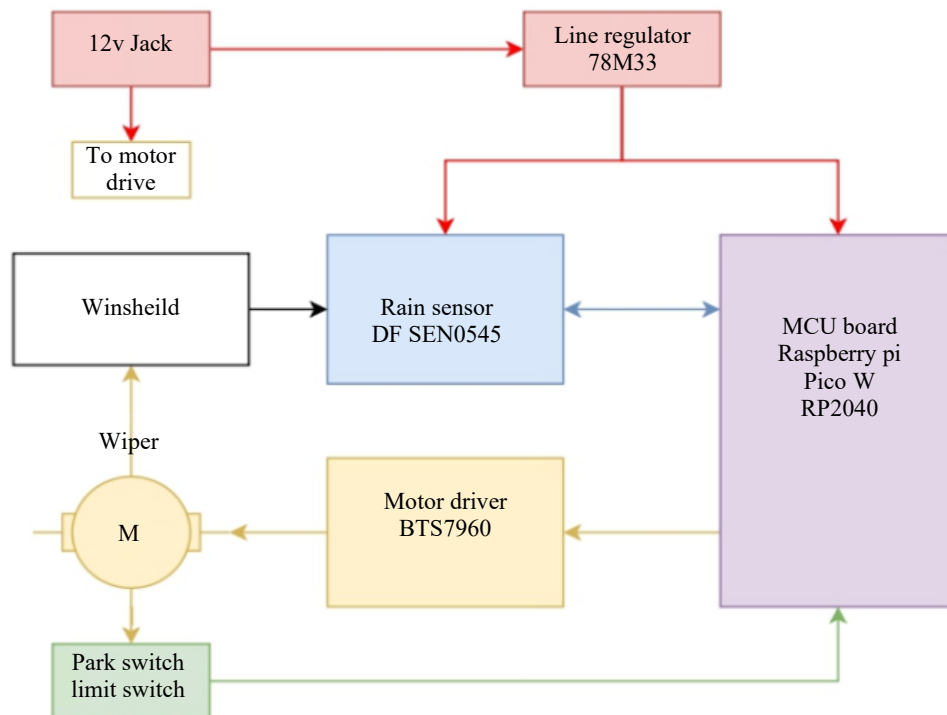


Figure 3. Block diagram of the proposed automatic rain-sensing wiper system showing the signal flow from sensing to actuation.

Table 5. Bill of materials and cost analysis.

S.N.	Component	Specification/description	Quantity	Price (INR, incl. GST)
1	Rain Sensor	DFRobot, SEN0545 Rain Sensor Module	1	2820.00
2	Microcontroller	Raspberry Pi Pico W	1	646.64
3	Motor Driver	BTS7960 Dual H-Bridge Module		442.50
4	DC Gear Motor	12V, 30 RPM Worm Gear DC Motor	1	2250.00
5	Shaft Coupling	Flexible Coupling 5mm × 8mm	1	64.99
6	Shaft Coupling	Aluminum NEMA17 Coupling 5mm × 8mm	1	85.00
7	Fasteners	M4 Allen Bolt Set (25 pcs)	1 set	147.50
8	DC Power Adapter	12V, 5A Adapter	1	460.20
9	Acrylic Windshield	Transparent Acrylic Sheet 3 ft × 2.5 ft	1	650.00
10	Aluminum	Aluminum sections, total 2.8 kg	-	785.00
				Total=8352

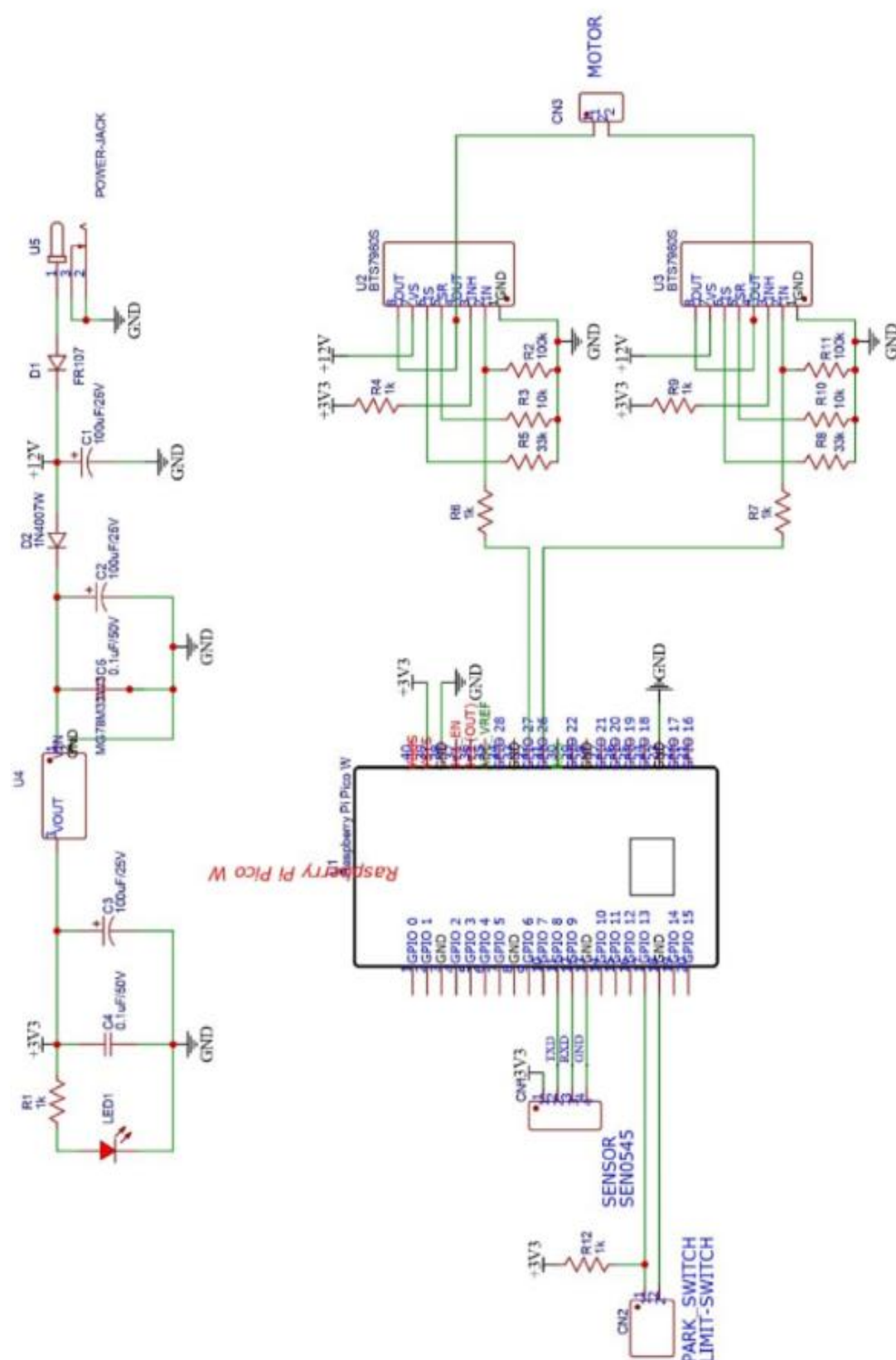


Figure 4. Circuit diagram showing the interfacing of the SEN0545 sensor, Raspberry Pi Pico W, motor driver, and DC gear motor.

Control Algorithm

- *Step 1:* Initialize the SEN0545 sensor, Raspberry Pi Pico W, motor driver, and peripherals.
- *Step 2:* Continuously sample sensor output.
- *Step 3:* Apply digital filtering.
- *Step 4:* Compare values with threshold levels.
- *Step 5:* Classify rain intensity.
- *Step 6:* Select wiping mode.
- *Step 7:* Generate motor control signal.
- *Step 8:* Drive gear motor.
- *Step 9:* Monitor sensor continuously.
- *Step 10:* Stop motor and park wiper when rain ceases.

Experimental Results and Analysis

The prototype was tested under controlled and real-time rainfall conditions to evaluate its sensing performance, control reliability, and mechanical operation. The SEN0545 rain detection module showed a fast response to rainfall onset, accurate rain-state classification, and stable digital output without false triggering. UART communication with the Raspberry Pi Pico W remained reliable, ensuring consistent real-time data processing. The embedded control algorithm (Figure 5) correctly executed delay-based wiping for light-, moderate-, and heavy-rain conditions, with smooth transitions between the operating modes. Figure 6 shows a graph illustrating the relationship between the detected rain intensity levels and the corresponding wiper motor speed.

The motor driver and DC gear motor demonstrated stable electrical and mechanical performances, providing smooth torque delivery, controlled speed variation, and vibration-free wiping motion. The mechanical linkage and limit-switch feedback system ensured accurate cycle completion and precise return-to-park positioning. Power management testing confirmed stable voltage regulation under varying load conditions. Overall, the system exhibited reliable automation, fast response, stable control, and consistent mechanical performance, validating the effectiveness and robustness of the proposed automatic rain-sensing wiper system [2, 3, 10]. The system achieved an average rain detection response time of approximately 100 ms, and the adaptive control mechanism successfully adjusted the wiping speed according to the rainfall intensity, ensuring smooth transitions between the operating modes. No false triggering was observed during testing, indicating a reliable and stable system performance. Tables 7 and 8 show the experiment and result observations. Figure 7 shows a photograph of the experimental prototype setup used for system testing and performance validation.

Table 6. Specifications of components.

Component	Specification
SEN0545 Sensor	Capacitive, UART
Raspberry Pi Pico W	RP2040, Wi-Fi
DC Gear Motor	12V, 30 RPM
Motor Driver Module	L298N / L293D
Power Supply	5V/12V regulated

Table 7. Experimental observations.

Test Condition	Result
Light rain	Successful
Moderate rain	Successful
Heavy rain	Successful
No rain	Wiper parked

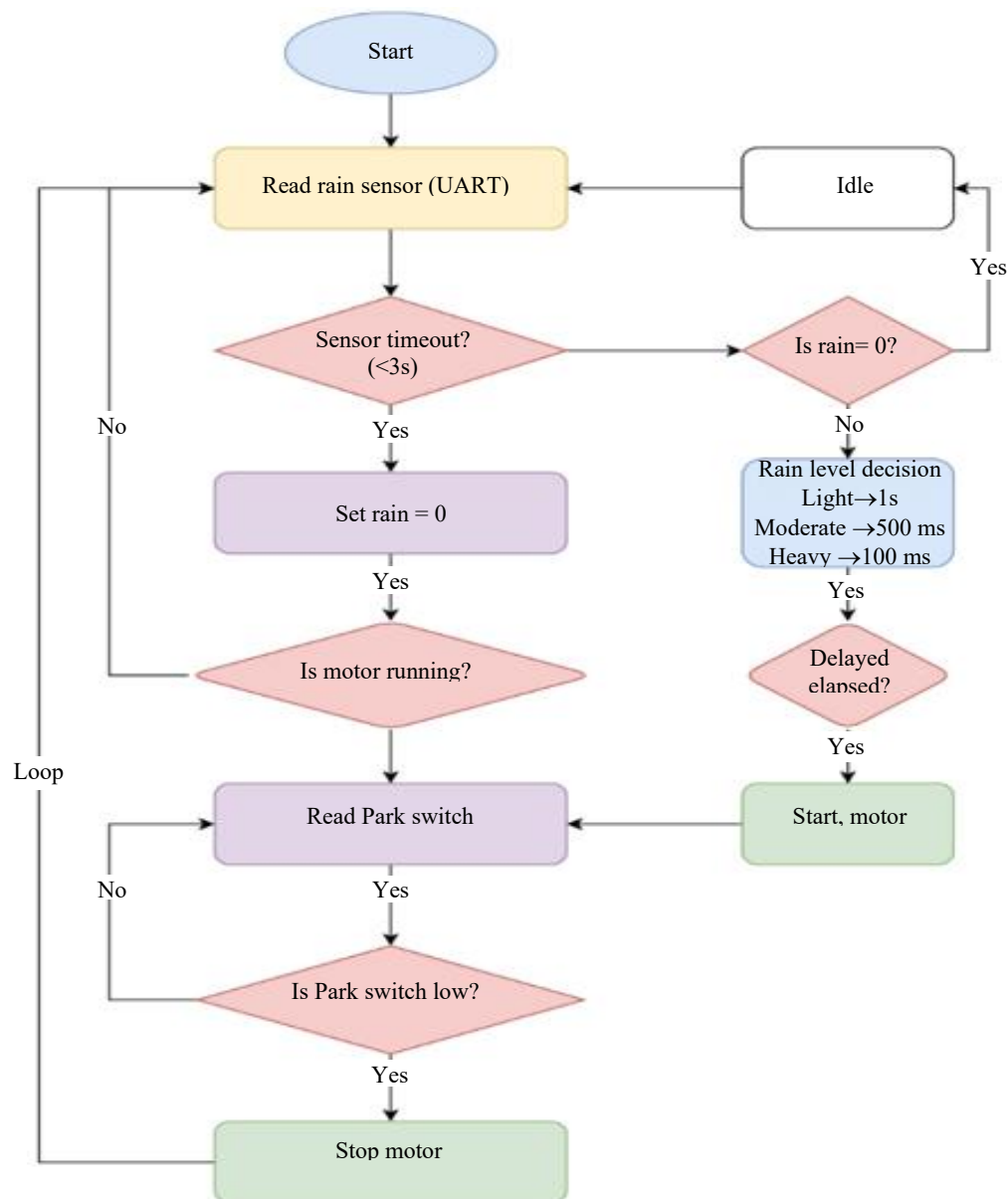


Figure 5. Flowchart of the embedded control algorithm illustrating the decision logic for adaptive wiper speed control.

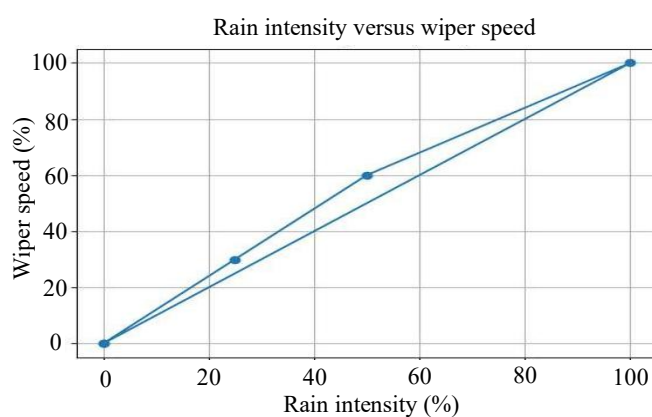


Figure 6. Graph illustrating the relationship between detected rain intensity levels and corresponding wiper motor speed.

Table 8. Result table.

Rain intensity	Sensor output level	Wiper delay time	System response
Light Rain	Level 1	1000 ms	Slow intermittent wiping
Moderate Rain	Level 2	500 ms	Medium speed wiping
Heavy Rain	Level 3	100 ms	Continuous fast wiping

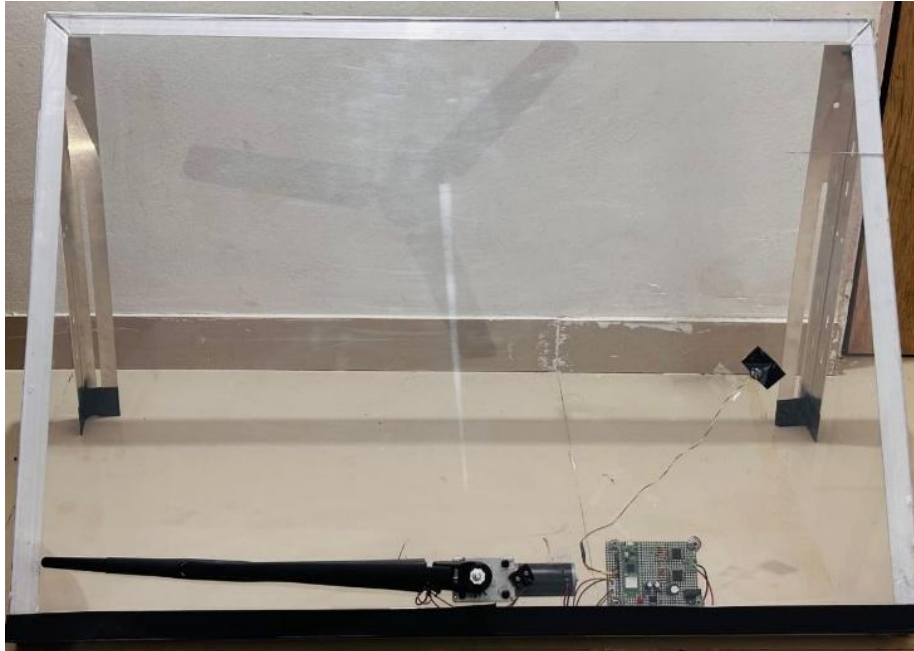


Figure 7. Photograph of the experimental prototype setup used for system testing and performance validation.

CONCLUSIONS

This paper presents the design, implementation, and experimental validation of an automatic rain-sensing wiper system based on intelligent digital sensing, embedded control, and adaptive electromechanical actuation. The proposed architecture integrates a smart rain detection module, embedded microcontroller-based control unit, rule-based control algorithm, and gear motor-driven actuation mechanism with mechanical feedback, forming a closed-loop automated wiper control system. The experimental results obtained under controlled and real-time rainfall conditions demonstrated reliable rain detection, stable digital communication, accurate control execution, and robust mechanical performance. The system exhibited a fast response to rainfall onset, consistent real-time processing, and stable adaptive wiping behavior across different rainfall intensities.

The integration of delay-based control logic enables smooth transitions between intermittent, periodic, and continuous wiping modes. Furthermore, the gear motor-based actuation system combined with limit-switch feedback ensured precise mechanical positioning, accurate return-to-park operation, and long-term operational stability. The power regulation and electrical performance remained stable under varying load conditions, confirming the reliability of the system. Overall, the proposed system demonstrates a scalable, reliable, and intelligent automation framework for windshield wiper control, significantly reducing the driver's workload and improving operational safety. The modular design and embedded intelligence make the system suitable for integration into smart vehicles, intelligent transportation systems, and future autonomous mobility platforms. Future work will focus on sensor fusion, predictive rain detection, adaptive learning-based control strategies, and integration with advanced driver-assistance systems (ADAS) to further enhance the system intelligence and reliability [5, 6, 9]. The developed system ensures a reliable, efficient, and scalable solution for automated windshield wiper operation in modern intelligent vehicles.

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