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RESEARCH ARTICLE OPEN ACCESS

EXPERIMENTAL STUDY ON SEMI-AUTOMATIC PARKING BRAKE SYSTEM FOR COST-EFFECTIVE PASSENGER VEHICLES

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ABSTRACT

The Semi-Automatic Parking Brake (SAPB) has been developed to enhance safety, reliability and convenience by replacing the conventional manual handbrake with an electronically controlled system. It integrates a microcontroller, actuator motor, sensors, and a control unit to function in a coordinated manner. When the vehicle ignition is switched on, the brake is released automatically and when the ignition is turned off, the brake engages and locks securely. The system was evaluated under various operating conditions, including level roads, uphill and downhill gradients, as well as emergency scenarios such as power loss or sensor malfunction. Test results demonstrated rapid operation, sufficient braking force and consistent performance across all conditions. Even under challenging circumstances, the SAPB maintained stability and ensured vehicle safety. Compared with traditional handbrakes, the system provides greater automation, improved precision, and higher dependability, making it a suitable solution for cost-effective passenger vehicles.

I. INTRODUCTION

The brake which can be utilized for the halting the vehicle amid dynamic and to avoid the collision. The auxiliary brake which is a crisis or stopping brake utilized for deceleration within the occasion of essential brake failure. In vehicles the hand brake could be a locking brake utilized to keep the vehicle stationary and to secure the vehicle still during stopping. Commonly usual to avoid the rolling of vehicle. In most of the vehicles the stopping brake worked as it were in real wheels which are utilized to diminish the traction whereas braking. The manual crisis brake utilized for stopping the vehicle. There are four types of stopping adhere lever found in older vehicles and put beneath the instrument board, center lever found in more up to date demonstrate vehicles found between the seats, pedal which is found to the cleared out of the brake pedals on the floor, electric button which is utilized in progressed vehicles which is found on support. The independent crisis braking system may be an exceedingly successful strategy for decreasing the event and costs related with activity accidents, especially those caused by rear-end collisions. These collisions are consequently recognized and cautioned around when the driver is occupied.

Over the past few a long time, programmed crisis braking frameworks have been broadly actualized in automobiles to upgrade security, as drivers frequently depend on these dynamic security highlights. The creation of semi-automatic parking brake systems for inexpensive cars has shown good results in making safety and cost work together. Modern semi-automatic parking brake systems are made in a way that keeps costs low while still meeting strict safety rules [1]. Adding safety features to cheaper cars has made parking easier and safer, without making the cars too expensive [2]. Special solutions for budget cars make production simpler and improve both convenience and safety, as shown by real tests [3], [4]. Combining semi-automatic brakes with safety sensors works well, keeping things simple but dependable, so the brakes work reliably in different situations and car stability help stop the car from moving by itself. [5], [6]. Fixing problems with cost and rules, had been led to smarter use of materials, and designs making sure performance stays high without going over budget, parking brakes faster and more reliable without costing too much [7], [8]. Modular designs, for basic vehicles follow safety rules are simple to use and keep costs low [9], [10].

All these studies together show big progress in car safety, material use, and system improvements. Systems that watch for driver conditions were tested and found to improve safety by identifying tiredness and distraction, lowering accident chances in cars [11]. Better safety systems that track the driver in real time help prevent accidents by warning drivers about unsafe situations [12]. New braking system ideas, like using delay valves and combining braking systems, help control the car better and stop it faster, making roads safer [13]. The importance of materials in car safety and how well they work is shown by research on how materials dampen tool vibrations [14] and how bio-composites and mixed joints behave, leading to stronger, lighter, and longer-lasting car parts [15], [16]. The study looks at how well a five-point seat belt and barking mechanism works during a front collision. It shows that this type of belt provides better protection for the user and results in fewer injuries than the usual three-point belt [17]. The paper also looks at how changing the shape of small channels in heat exchangers used for car air conditioning affects performance. The results show that using the right design for the channels and fins can make the system work better and reduce pressure in the refrigerant [18].

Occupant safety is also improved through the design and testing of better seat belt systems, which can reduce the seriousness of injuries in front collisions [19]. Using IoT technology in the automotive industry allows for real-time monitoring of a vehicle's condition and helps predict when maintenance is needed, making driving safer [20], [21]. Research on energy cogeneration, even though it's not directly related to cars, offers sustainable ideas that might shape future vehicle power systems [22]. Automatic emergency braking systems that use hydraulic actuators show they can prevent accidents in dangerous situations [23]. Surveys on motorcycle rider fatigue help identify risk factors and guide the creation of systems that detect fatigue [24]. The research shows that using ANSYS to improve the materials in suspension systems makes the suspension on two-wheelers better and lasts longer [25], [26]. Lastly, improvements to the front parts of vehicles were explored to lower injury risk in bus crashes, showing how important structural design is for protecting passengers [27]. The test results show that the Semi-Automatic Parking Brake system works quickly and reliably in different situations, which helps make the car safer and more stable and additionally this study looks at ways to make passenger cars safer by improving the braking system. It shows that better braking systems can help cars stop faster and lower the chance of accidents [28], [29].

III. MATERIALS AND METHODS

The conventional stopping brake development is most well-known and broadly utilized in low duty vehicles, the mechanisms similar to the proposed system. The only distinction is rather than physically operated, it is operated by ignition key status and switch mode (button worked) by the support of electronically motorized actuator parking brake. There are two modes for working the handbrake, one for starting/stopping conditions and the moment one for dynamic/slope conditions. During starting/stopping parking brake is worked by the ignition key and switch mode for the slope and dynamic condition. The stopping lever arm rotated on a ratchet when the motorized actuator pulls up hand brake lever arm, the spring-loaded pawl runs or slides over the teeth of the ratchet causes most extreme tension on the cable and the brake is connected. To discharge the brake pressure on the pawl teeth turned on the ratchet teeth this causes the stopping brake lever to return completely down to the discharged or typical position. The format of semi-automatic parking brake is appeared within the figure 1. The ignition key is utilized to function the handbrake to lock in and separate the lever arm during request. When the ignition key is ON the signal from the controller actuates the actuator to discharge the parking brake lever. When the ignition key is turned OFF the actuator locks in or pulls up the stopping lever and the brake is connected.

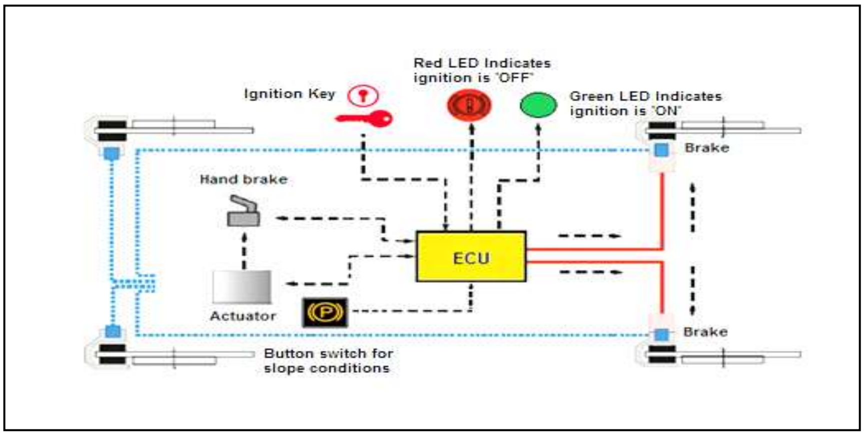

Figure 1: Layout of Semi-Automatic Parking Brake System (SAPB).
Source: Authors, (2025).

III.1 SYSTEM DESIGN FOR CONTROLLING A SEMI-AUTOMATIC PARKING BRAKE

The Semi-Automatic Parking Brake (SAPB) control system is built around the Arduino microcontroller board, utilizing the ATmega328P microcontroller chip as its core processing unit. This microcontroller works at a voltage of 5V, with a suggested input voltage extend of 7-12V and an amplified extend of 6-20V. It highlights 14 digital input/output (I/O) pins, with 6 pins supporting heartbeat Width Modulation output, and 6 analog input pins for sensor integration. The system delivers a greatest DC current of 40mA per I/O pin and 50mA on the 3.3V pin, ensuring reliable power management for associated peripherals. The ATmega328P gives 32KB of flash memory for program capacity, 2KB of SRAM for runtime information, and 1KB of EEPROM for non-volatile data maintenance. The microcontroller operates at a 16 MHz clock speed, allowing it to process and control information in real time. The SAPB system includes extra parts like a motor for braking, a hand lever mechanism, and a battery control system. All these parts work together under the microcontroller's control to carry out important SAPB functions such as automatic parking tests, hold function tests, and emergency brake tests. The system adapts well to different road conditions and slopes.

It ensures precise motor control, checks sensor feedback, and performs safe braking operations. This setup improves efficiency, reliability, and ease of use in modern vehicles. The green LED flickers and it demonstrates vehicle is in off condition which suggests ignition key is in off. The figure 2 (b). demonstrates vehicle is in ON or idling and the stopping lever is in released conditions. These two conditions are for plain road which shows that the programmed release and locked in. The ignition key works the parking lever when to lock in or disengage in plain road and the system is worked naturally. The reaction time for the proposed system is upgraded than the routine system. The model setup demonstrates the position of lever in engaged position had appeared in figure 2 (a).

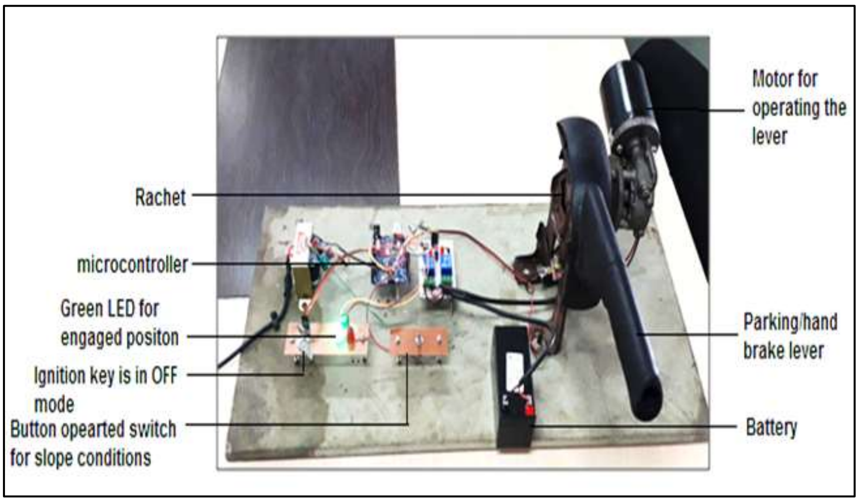

Figure 2:(a) Brake lever engaged position.
Source: Authors, (2025).

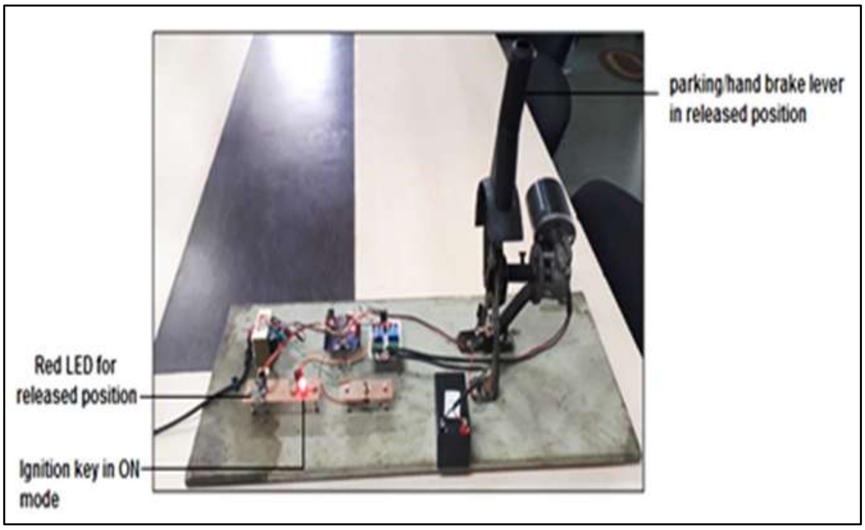

Figure 2:(b) Brake lever disengaged position.
Source: Authors, (2025).

III.1.1 Experimental Setup Model of Sapb

The experimental model of the Semi-Automatic Parking Brake (SAPB) system is developed to analyse the functionality, responsiveness, and reliability of an automated braking mechanism controlled through an ignition key and motorized operation. The system consolidates a 12V DC engine, an Arduino microcontroller, a motor driver module, and sensors such as position and force sensors to empower precise control and feedback during brake engagement and release. The ignition key is the main part that starts or stops the parking brake using the motor actuator. The Semi-Automatic Parking Brake (SAPB) uses sensors to check real-time conditions like flat, uphill, or downhill roads and makes adjustments to the braking. From the Table 1. The Semi-Automatic Parking Brake (SAPB) engages and releases by the ignition key by using a DC motor controller and to ensure smooth and reliable operation.

A 12V gear motor where produces 15-25 Nm torque and 60–100 RPM of worm gear to prevent the back drive and with the thermal protection and encoders for the safety precision. A motor controller uses a L298N H-Bridge IC operates at 6–24 V with pulse width modulation support to narrow or regulate the speed of the motor, torque and direction. Microcontroller like the ATmega328P (Arduino) provides the feedback or command, which processes data from the ignition key and multiple sensors. Inputs from the position sensor, slope sensor and force sensors allow the electronic control unit to adapt the braking performance to road conditions, ensuring accurate and dependable control. Safety elements such as locks, switches, and manual controls ensure the system is dependable, making the SAPB a strong and effective way to improve braking and vehicle safety.

III.1.2 Design Parameters for Engaging and Disengaging the Hand Brake Using Ignition Key (ON/OFF).

Table 1: Design Parameters for Hand Brake Engagement and Release Based on Ignition Key Status.

Parameter	Ignition Key ON (Disengage Hand Brake)	Ignition Key OFF (Engage Hand Brake)	Description
Ignition Voltage	12.0 V ± 0.5 V	0 V	Voltage levels detected by the ECU.
Signal Detection Delay	≤ 50 ms	≤ 50 ms	Time taken to detect ignition key state.
Brake Engagement/ Disengagement Time	1-2 sec	0.1-0.2 sec	Time required for full brake action.
Brake Actuator Type	Electromechanical Actuator	Electromechanical Actuator	Type of actuator used for brake control.
Brake Force Applied	2000-2500 N	2000-2500 N	Force applied on brake pads/discs.
System Feedback Signal	Brake Disengaged Signal: 5 V	Brake Disengaged Signal: 5 V	Signal sent to dashboard indicators.
Manual Override Response Time	≤ 500 ms	≤ 500 ms	Manual override response speed.
Control Logic Response Time	≤ 100 ms	≤ 100 ms	ECU processing and decision time.
Safety Lock Condition	Accelerator Depressed: No Action	Brake Locked	Conditions to prevent unsafe operation.
Error Detection Mechanism	Brake Disengagement Error: Alert	Brake Disengagement Error: Alert	Alerts for system malfunction.
System Power Consumption	≤ 20 W	≤ 20 W	Power consumed by the brake actuator.
Failsafe Operation	Engage Automatically on Fault	Engage Automatically on Fault	Behaviour during power loss or fault.
Sensor Type	Position Sensor & Ignition Status Sensor, inclination sensor, force sensor	Position Sensor & Ignition Status Sensor, inclination sensor, force sensor	Sensors used to detect states.
Environmental Tolerance	-10°C to 60°C	-10°C to 60°C	Operating temperature range.

Source: Authors, (2025).

IV. RESULTS AND DISCUSSIONS

IV.1 EXPERIMENTAL VERIFICATION AND TESTING RESULTS

The experimental testing was done using a Ford Figo passenger car that weighs about 1040 kg. The wheel radius is 0.3 meters, there are 4 wheels, the engine has a capacity of 1200cc, produces a maximum power of 95 Bhp, and a maximum torque of 119Nm. It has 3 cylinders. The semi-automatic stopping brake system flowchart is shown in Figure 3, which explains the different testing methods and conditions. The process began by setting up the equipment and introducing the components, including the controller and stopping lever, into the vehicle. Following the establishment, tests were performed beneath both level street and inclined street conditions. The SAPB control software and signal preparing systems were executed to oversee the brake operations. Beneath level road conditions, a semi-automatic stopping test and a hold function test were conducted. For the inclined road, a hold function test was performed, with brake engagement activated by a button. Finally, an emergency brake test was carried out to assess the system's reaction to sudden braking forces, guaranteeing its usefulness and execution in emergency circumstances.

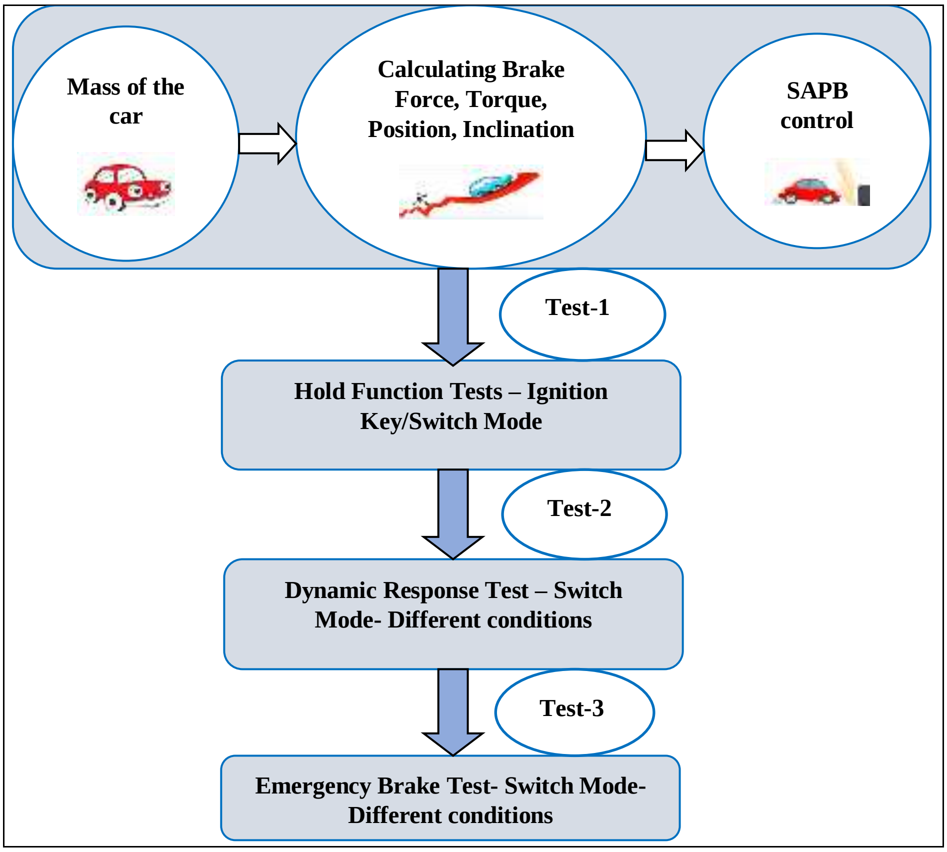

Figure 3: Flowchart of SAPB
Source: Authors, (2025).

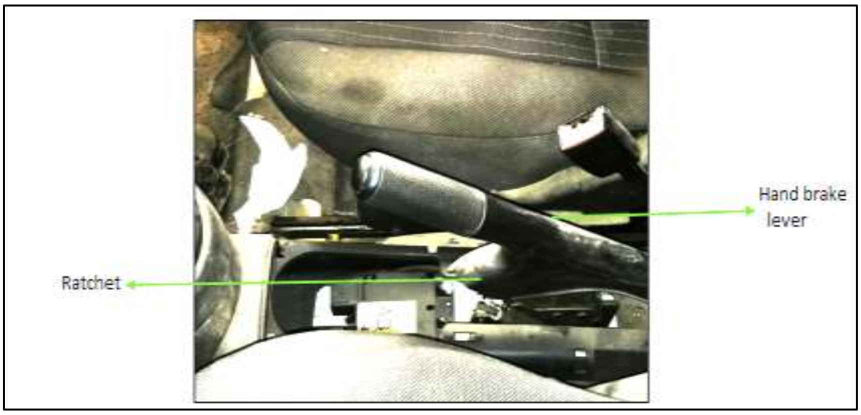

Figure 4: Parking brake lever setup connected in figo vehicle.
Source: Authors, (2025).

The figure 4 outlines the brake lever assembly safely settled within the vehicle, exhibiting its integration within the overall semi-automatic parking brake system. The lever is placed in a way that makes it easy and comfortable to use, so both manual control and automatic operation can be done smoothly. The way it is attached makes sure the structure is strong enough to handle the forces when the brake is applied or released. The design also allows for sensors to be added, which helps keep track of the lever's position and whether the brake is on or off. The whole setup is made to work efficiently while reducing vibrations and wear, which makes the braking system more durable and dependable. The semi-automatic braking system works with the ignition key—when it's turned on, the brake releases quickly, letting the vehicle move freely.

If the brake is released too fast, safety features prevent it from unlocking if the accelerator is pressed suddenly. When the ignition is turned off, the brake engages quickly, holding the vehicle in place even on slopes up to 15%. The dashboard shows real-time information about the brake's status so the driver can always know what's happening. The system consolidates manual override functionality, permitting the driver to physically control brake engagement or disengagement with a reaction time of ≤500 ms. Moreover, a failsafe mechanism guarantees automatic brake engagement during power failures or detected flaws, avoiding unintended vehicle development. With a control logic reaction time of ≤100 ms and operation stability across changing natural conditions (-10°C to 60°C), the system ensures dependable performance under diverse scenarios, optimizing both security and

Table 2: Time and velocity table for semi-automatic parking brake system (SAPB).

Test condition	Time (sec)	Expected Velocity (m/s)	Description
1. Ignition OFF to ON (Brake Disengagement	1-2 sec (for brake disengagement)	0 m/s (vehicle stationary)	Parking brake should disengage after ignition is turned ON. The vehicle should be stationary during this time.
2. Ignition ON to OFF (Brake Engagement)	0.1-0.2 sec (for brake engagement)	0 m/s (vehicle stationary)	Parking brake should engage within 100-200ms of ignition OFF. No movement of the vehicle.
3. Manual Disengagement of Brake	0.5 sec (manual override time)	0 m/s (vehicle stationary)	When manually disengaging the brake, the vehicle should remain stationary until full disengagement occurs.
4. Power Loss (Brake Engaged)	1-2 sec (for recovery)	0 m/s (vehicle stationary)	The vehicle should remain stationary during power recovery, with the brake still engaged.
5. Emergency Override (Brake Engaged)	0.1-0.2 sec (for brake engagement)	0 m/s (vehicle stationary)	Emergency override should engage the brake immediately and keep the vehicle stationary.
6. Hold Function Active (Ignition ON)	0 sec (no delay)	0 m/s (vehicle stationary)	The vehicle should remain stationary with the hold function active. No movement should occur.
7. Hold Function Active (Ignition OFF)	0 sec (no delay)	0 m/s (vehicle stationary)	The vehicle should remain stationary with the hold function active even after the ignition is turned off.
8. Ignition ON and Engine Start	1-3 sec (for smooth engine start)	0 m/s (vehicle stationary)	Engine start should not interfere with the hold function; the vehicle should stay stationary.
9. Multiple Ignition Cycles (Quick)	0.5 sec (cycle time)	0 m/s (vehicle stationary)	Rapid switching between ON/OFF should not cause failure, and the vehicle should remain stationary.
10. Vehicle on Incline (Brake Engagement)	0.1-0.2 sec (for brake engagement)	0 m/s (vehicle stationary on incline)	Brake should engage immediately and hold the vehicle stationary on a given incline (e.g., 5%, 10% and 15%).
11. Low Battery Voltage (Brake Holding	0 sec (no delay)	0 m/s (vehicle stationary)	Brake should hold the vehicle stationary even under low battery conditions (e.g., below 10.5 V).
12. Battery Voltage Drop (Brake Disengaged)	1 sec (recovery time)	0 m/s (vehicle stationary)	If the system detects low voltage, the brake should engage automatically to prevent unintended movement.

Source: Authors, (2025).

The Table 2. Describes the timing and speed parameters for the semi-automatic parking brake system (SAPB). The stopping brake should release consequently when the ignition is switched ON, guaranteeing the vehicle remains stationary, and should re-engage inside 100-200 ms when the ignition is turned OFF, anticipating any movement. Manual disengagement must not permit the vehicle to move until the brake is completely released. During power recovery, emergency override activation, or when the hold function is active, the vehicle must remain immobile. The brake should securely hold the vehicle stationary on various inclines (e.g., 5%, 10%, and 15%) and even under low battery conditions, engaging automatically if a drop in voltage is detected. The activation of the engine or rapid switching between ON/OFF states should not disrupt these functionalities.

IV.2 HOLD FUNCTION TESTS IN PLAIN ROAD CONDITIONS

The semi-automatic parking brake (SAPB) test is conducted under plain road conditions to evaluate the system's performance in scenarios with minimal external resistance. The control system and the experimental test car are illustrated in Figure 4. The test vehicle, weighing approximately 1040 kg, Wheel Radius (r) = 0.3m, Number of Wheels (n) = 4, Incline Angle (θ) = Variable (0° to 30°) is positioned on a flat surface with good adhesion conditions to ensure accurate measurements and repeatable results. During the test, the response time for releasing and engaging the parking brake lever is carefully measured. When the ignition key is turned ON, the stopping lever disengages, and the braking force is discharged, permitting the vehicle to begin moving unreservedly. Alternately, when the ignition key is turned OFF, the stopping lever remains engaged, effectively securing the vehicle in place. The reaction time of the proposed Semi-Automatic Parking Brake (SAPB) system is measured and compared with a conventional stopping brake system. The results show that the SAPB system completely releases the stopping lever in around 2 seconds, illustrating a quicker reaction time compared to routine systems. This change highlights the productivity and improved operational execution of the SAPB framework beneath standard driving conditions. The Figure 5 appears the stopping brake lever reaction with regard to time taken and it has been compared with the routine system time taken.

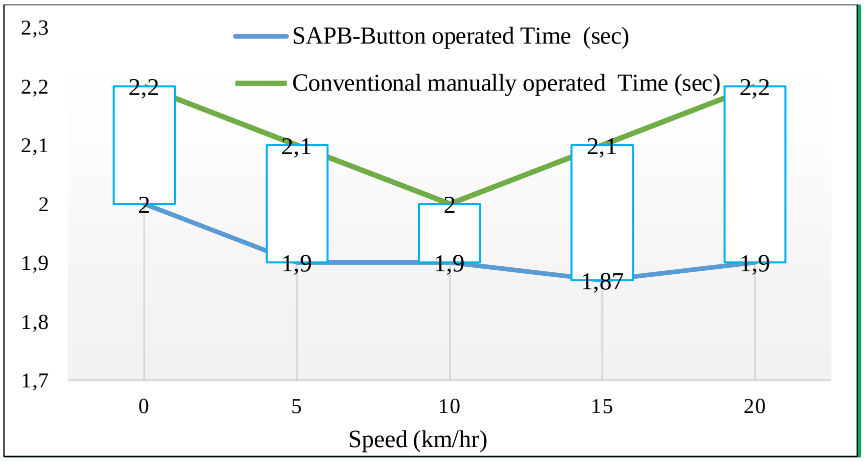

Figure 5: Comparison of SAPB vs Conventional parking brake response with respect to time.
Source: Authors, (2025).

IV.2.1 Torque Validation Test

Table 3: Torque vs Time for Brake Engagement.

Motor Torque (Nm)	Time to Engage Brake (s)	Time to Disengage Brake (s)	Remarks
10	12	10	Low torque, slower brake engagement
50	6	5	Moderate torque, faster engagement
100	4	3	Higher torque, faster engagement
153	3	2	Required torque for brake engagement
200	2.5	2	High torque, very fast engagement
300	2	1.5	Maximum motor torque for quick braking
500	1.5	1	Very high torque, fastest engagement

Source: Authors, (2025).

The Table 3. Demonstrates the relationship between motor torque and the time required to engage and disengage the parking brake. The motor torque applied to the brake lever determines how quickly the brake is engaged or released. As the torque applied by the motor increases, the time required to engage or disengage the brake decreases. For example, at a lower torque of 10 Nm, the brake takes longer to engage (12 seconds) and disengage (10 seconds) compared to when the torque is higher, such as 153 Nm, where the time to engage and disengage the brake is much shorter (3 seconds and 2 seconds, respectively). The table 3. Assumes a simplified linear relationship, where higher torques result in faster brake engagement times, demonstrating the efficiency of applying more force. However, in a real-world scenario, the relationship could be influenced by factors like motor speed, mechanical advantage, friction, and other system characteristics. This table helps visualize the expected behaviour of the motor-driven brake system under different torque conditions, aiding in the design of the system for optimal performance.

Table 4: Required Parking Brake Torque on Downhill Slopes.

Incline Angle (°)	Downhill Force (N)	Force per Wheel (N)	Required Torque per Wheel (Nm)
0	0	0	0
5	892.9	223.2	66.96
10	1,768.4	442.1	132.63
15	2,643.9	660.98	198.29
20	3,519.4	879.9	263.97
25	4,394.8	1,098.7	329.61
30	5,270.3	1,417.6	395.28

Source: Authors, (2025).

The Table 4 and 5 and figure 6 shows the required parking brake torque for a vehicle facing downhill and uphill. When a vehicle is parked uphill, the parking brake must generate sufficient torque to counteract the gravitational force pulling the vehicle downward. The calculations for uphill conditions are identical to downhill conditions because the gravitational force acts along the same axis but in the opposite direction.

Table 5: Required Parking Brake Torque for a Vehicle Facing Uphill.

Incline Angle (°)	Uphill Force (N)	Force per Wheel (N)	Required Torque per Wheel (Nm)
0	0	0	0
5	892.9	223.2	66.96
10	1,768.4	442.1	132.63
15	2,643.9	660.98	198.29
20	3,519.4	879.9	263.97
25	4,394.8	1,098.7	329.61
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Source: Authors, (2025).

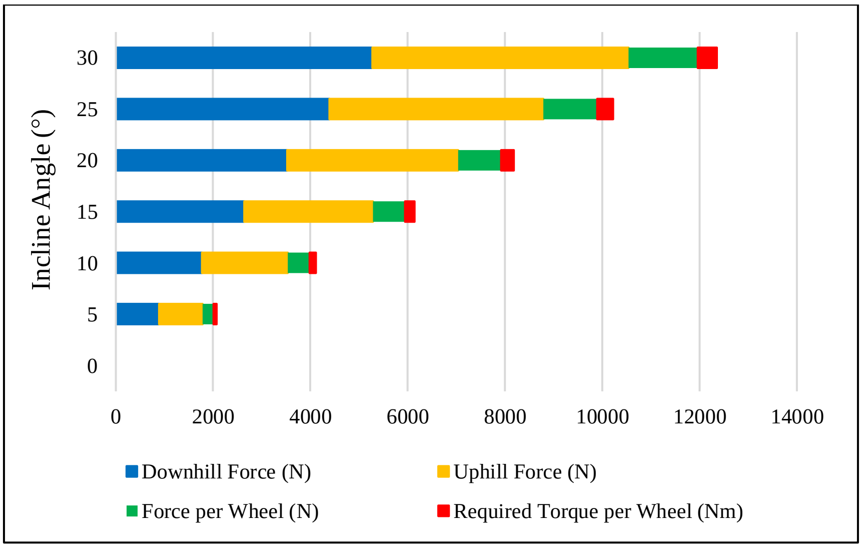

Figure 6: Parking Brake Torque/force for a Vehicle Facing Uphill/Downhill.
Source: Authors, (2025).

IV.2.2 Comparison of Parking Brake Torque for Uphill and Downhill Scenarios

From the Table 6, 7 and figure 7 describes the Uphill engagement times are slightly longer than downhill due to the greater force required to hold the vehicle from rolling backward. When analysing the parking brake torque requirements for a vehicle facing uphill and downhill, it is evident that both scenarios demand sufficient braking force to counteract the gravitational pull acting on the vehicle. In both cases, the torque required depends on factors such as vehicle mass, slope angle, wheel radius, and braking system efficiency. For a vehicle with a mass of 1040 kg parked on a 10° incline, the calculated torque per wheel to hold the vehicle stationary is approximately 133 Nm. However, there are slight differences in the engagement and disengagement times between uphill and downhill conditions. When facing downhill, the parking brake primarily prevents the vehicle from rolling forward, and the motor torque builds up relatively smoothly, resulting in a faster engagement and disengagement time compared to uphill.

On the other hand, in uphill scenarios, the motor must neutralize a slightly higher resistance caused by the gravitational drag acting inverse to the intended brake force direction. Subsequently, the engagement and separation times tend to be marginally longer uphill compared to downhill for the same motor torque. In rundown, whereas the specified braking torque remains comparable for both uphill and downhill stopping conditions at a given incline, the time taken to completely engage or release the brake uphill is marginally longer due to the extra gravitational resistance. Optimizing motor torque and control logic can offer assistance decrease these engagement delays and ensure solid braking performance in both scenarios.

Table 6: Parking Brake Torque vs. Time (Downhill, 10° Slope).

Torque (Nm)	Time to Engage Brake (s)	Time to Disengage Brake (s)	Remarks
50	6	5	Insufficient for full hold
100	4	3	Partial hold achieved
133	3	2	Optimal hold for 10° slope
150	2.5	1.8	Faster engagement
200	2	1.5	Very quick engagement
300	1.5	1	Maximum motor efficiency
500	1	0.8	Over-engineered (Excess power)

Source: Authors, (2025).

Table 7: Parking Brake Torque vs. Time (Uphill, 10° Slope).

Torque (Nm)	Time to Engage Brake (s)	Time to Disengage Brake (s)	Remarks
50	6.5	5.5	Insufficient for full hold
100	4.5	3.8	Partial hold achieved
133	3.2	2.5	Optimal hold for 10° slope
150	2.7	2.0	Faster engagement
200	2.2	1.7	Very quick engagement
300	1.7	1.2	Maximum motor efficiency
500	1.2	0.9	Over-engineered (Excess power)

Source: Authors, (2025).

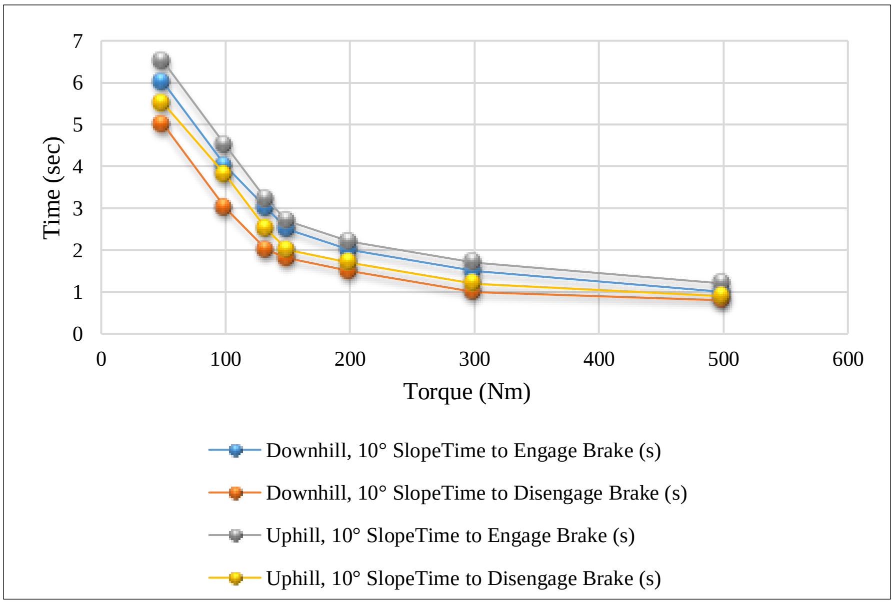

Figure 7: Parking Brake slope time engage/disengage for a Vehicle Facing Uphill/Downhill.
Source: Authors, (2025).

IV.2.3 SAPB Test in Dynamic Response Test-Button operated/Ignition key

Table 8 represents the dynamic response test results, calculating the time taken for the brake to engage and disengage under varying conditions. Therefore the motor torque, current and voltage were monitored, to evaluate proposed system performance. The tests were carried out in real driving environments to ensure accuracy and reliability. The results showed that uphill slopes required greater braking force, while plain road and downhill slope roads needed comparatively less. Overall, the SAPB system demonstrated smooth operation, quick response, and consistent reliability across all the tested conditions and the figure 8 represents the dynamic response test for different conditions.

Table 8: Experimental Values for Dynamic Response Test of Motor-Operated Parking Brake.

Test Condition	Ignition State	Brake State	Engagement Time (s)	Disengagement Time (s)	Motor Torque (Nm)	Motor Current (A)	Motor Voltage (V)	Remarks
Flat Road	ON	Released	2.5	2.0	130	5.2	12	Optimal operation
Flat Road	OFF	Engaged	2.7	2.7	135	5.4	12	Smooth engagement
Uphill (10° Incline)	ON	Released	3.2	3.2	140	6.0	12	Slight delay observed
Uphill (10° Incline)	OFF	Engaged	3.5	3.5	145	6.2	12	Higher torque required
Downhill (10° Incline)	ON	Released	2.8	2.8	128	5.5	12	Faster release observed
Downhill (10° Incline)	OFF	Engaged	2.9	2.9	132	5.6	12	Stable operation
Manual Override (Failure)	-	Released	-	-	-	-	-	Smooth manual release
Emergency Stop	OFF	Engaged	2.0	2.0	150	6.5	12	Rapid response achieved

Source: Authors, (2025).

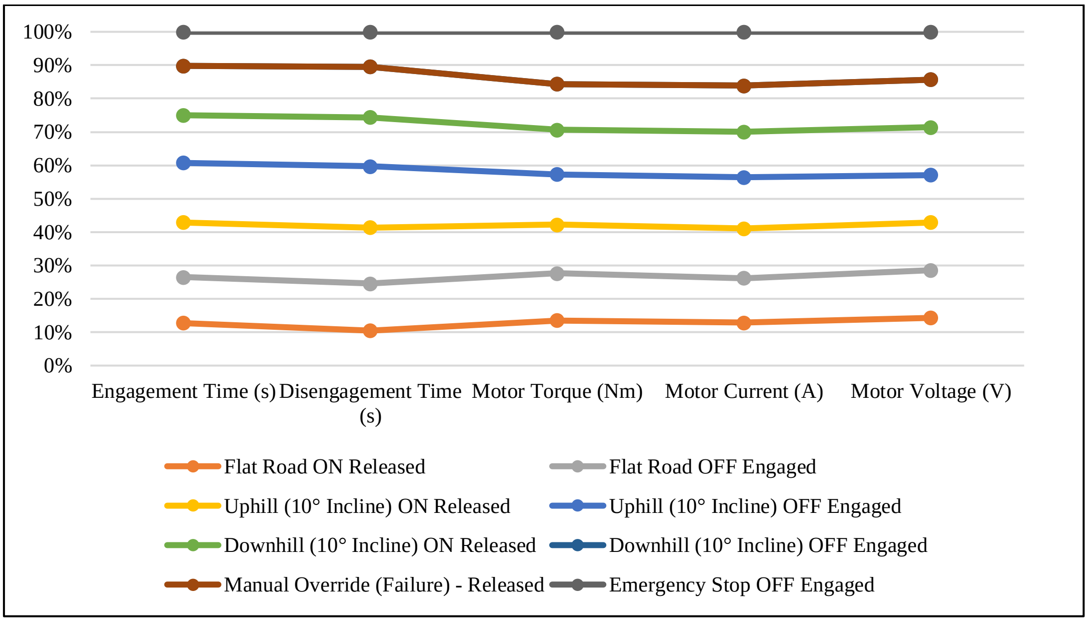

Figure 8: Dynamic Response Test for different conditions.
Source: Authors, (2025).

IV.2.4 Emergency brake test for the Semi-Automatic Parking Brake (SAPB)

Table 9 and figure 8 represents the emergency braking test results under the various conditions, including in the different road surfaces, slopes, sensor failures and vehicle instability. The tests evaluated the Semi-Automatic Parking Brake (SAPB) performance during emergency situations, such as ignition off, sensor malfunction, or sudden driver loss of control. The system consistently applied the brakes quickly with sufficient force to maintain safety and vehicle stability. On flat surfaces, braking occurred in about 3 seconds with 20-30 Nm, while uphill and downhill slopes required 3.5-4 seconds with 25-40 Nm. Even during sensor failures or loss-of-control scenarios, the SAPB engaged reliably within 4 seconds, confirming its effectiveness and robustness in emergencies

Table 9. Emergency Brake Test for Semi-Automatic Parking Brake (SAPB).

Test Condition	Trigger Mechanism	Engagement Time (s)	Disengagement Time (s)	Braking Force (Nm)	Vehicle Response
Flat Surface	Ignition failure (off)	3	2	20-30	Vehicle remains stationary
Uphill Gradient (5%)	Emergency override	4	3	25-35	Vehicle remains stationary
Downhill Gradient (5%)	Automatic trigger (sensor failure)	3.5	2.5	30-40	Vehicle remains stationary
Sensor Failure	Manual override activation	4	3.5	20-25	Vehicle remains stationary
Power Loss	Ignition off and failure of main brake system	4	3	35-45	Vehicle remains stationary

Source: Authors, (2025).

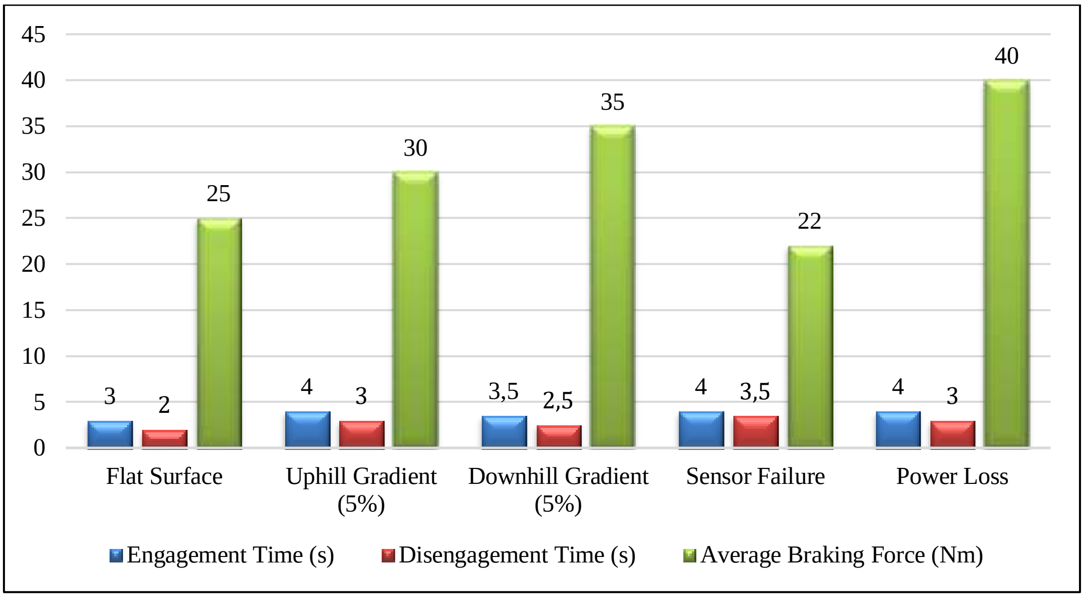

Figure 9: Emergency Brake Test for different conditions (SAPB).
Source: Authors, (2025).

V. CONCLUSIONS

The Semi-Automatic Parking Brake (SAPB) is developed to enhance vehicle safety, reliability and ease of use by substituting the conventional handbrake with an electronically controlled system. It consists of a microcontroller, motor, position sensors, and a control unit that work together for seamless operation. Upon turning on the ignition, the brake disengages automatically, and when the ignition is turned off, it engages and locks in place. The system was evaluated under various conditions, including level ground, uphill, downhill, and emergency situations such as power loss or sensor failures. Test results demonstrated rapid response, adequate braking torque, and consistent functionality across all scenarios. Even under challenging conditions, the SAPB preserved vehicle stability and ensured safety. Compared to traditional handbrakes, it delivers greater automation, accuracy, and reliability, positioning it as a viable solution for contemporary vehicles.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: C Dineshkumar, B Mustafa, S A Srinivasan, M Tabrez, V Ashmitha.
Methodology: C Dineshkumar, B Mustafa.
Investigation: C Dineshkumar, B Mustafa.
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