



ADAPTIVE PROPORTIONAL-INTEGRAL CONTROLLER DESIGN FOR VEHICLE ANTI-LOCK BRAKING SYSTEM (ABS)

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Abstract

The ability of the active braking system to maximize longitudinal friction between the tire and the road while preserving the high lateral forces that guarantee the vehicle's driving makes it an extremely important electromechanical system that greatly increases the vehicle's safety in harsh environments. Through trial and error, the controller demonstrated a satisfactory response, and the friction coefficient between the tire and the road was reduced by bringing the error between slip and ideal slip to zero. This research aimed to achieve a conventional proportional Integral (pi) control for the (ABS). However, abrupt changes in road conditions were beyond the controller's capacity to handle. Because extremum searching was used in the construction of the Modified Adaptive P controller, the reference is therefore adaptive when the road changes. The simulation's outcome demonstrated how effective the suggested controller was.

Keywords: ABS, PID controller, Adaptive PID, Extremum Seeking.

Introduction

Following the development of the first driven vehicle, particularly following the first driving accident, the engineers were resolved to increase the vehicle's safety. Thus, effective braking systems will lower the number of accidents. The 1930 aircraft industry's production of the first mechanical antilock braking systems inspired vehicle specialists to further this subject. All airplanes had Anti-lock Braking Systems (ABS) installed by 1950. [1]. An automobile safety feature that keeps the wheels from locking up and prevents uncontrollable skidding is an antilock braking system. Additionally, as seen in Figure 1, the ABS enables the wheels of the car to maintain tractive contact with the road surface in response to driver inputs during braking.

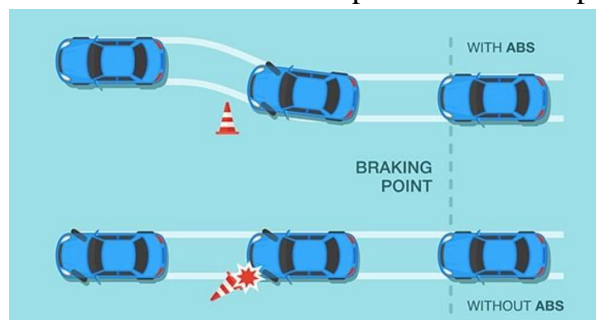


Fig.1. Sudden braking with and without ABS.



Where the automation of the ABS takes into consideration the concepts of threshold braking and cadence braking. ABS, which uses a modulator in each wheel to control the solenoid valves and speed sensors, improves vehicle control and reduces stopping distance in dry and slick conditions. ABS uses automated pumping in conjunction with a standard braking system. The driver must manually apply the brake in cars without ABS in order to avoid wheel locking. The driver's foot must stay firmly on the brake pedal for the ABS to pump the brake when the car is equipped with it. The wheel will slip and lock up under emergency braking or on slick roads, increasing stopping distance and possibly causing the vehicle to lose steering stability. Controlling wheel slip is the goal of ABS in order to maximize friction and steering stability. That is, to decrease the vehicle's stopping distance while maintaining directional control. The ideal goal for the controller design is to regulate the velocity of the wheel [1-3].

1.2 Adaptive Control

Adaptive control, which combines feedback and optimal control, can be defined as an auto-correcting type of control. The input and output process variables would be measured using an adaptive control system. In other words, an adaptive control system can automatically modify its parameters to account for changes in the properties of the process it regulates [3-5]. It would function as an ideal system when using the overall performance measurement after receiving specific feedback from the process variables. Adaptive control systems are specifically made to function in dynamic environments. As a result, it can assess how well the process is working and make adjustments to achieve the right outcome [5].

1.3 Research Problem

The public is concerned about the vehicle's smooth handling and braking stability, which calls for extra care. We are exposed to news about traffic accidents on a daily basis. On the streets, a lot of people get hurt or die. The brake pedal is used to manually operate the traditional braking mechanism. The driver's expertise and reflexes determine how successful it is, and the driver's age, gender, visibility, and other characteristics affect how quickly they react. Therefore, it is imperative that the braking mechanism be automated. Vehicles are equipped with automated safety braking systems, or ABS. Additionally, an ABS software system is a safety-embedded control system that communicates with a vehicle's hardware sensors and actuators from the standpoint of software engineering [4]. In addition to keeping the car's wheels from locking up, the ABS helps maintain the vehicle's directional control and enhances steering control when braking in emergency situations. Additionally, it shortens stopping distances on slick, dry surfaces. The parameters of stopping time and stopping distance are crucial in challenging situations where severe braking of a moving vehicle at high speed is necessary. This is because an accident can be avoided in a matter of seconds, and because the Classic PID is unable to keep up with the abrupt changes in the road, we had to use adaptive control. The goal is to do the following in order to create a strong control that reduces friction between the tire and the road:

Design classic PID control to reduce the error between the slip and optimal slip (the slip that maximizes fractions) to Adaptive the optimal slip (reference) for the PID control is the road change.



Finally, our study provides the ideas generated, the concepts applied, the activities performed, and the conclusions, and is organized into four sections. Below is a description of each section.

Section I, provides a general overview of the project and the use and importance of Anti-lock Braking Systems, the objectives and problem statement are also described in this section. Section II, we learn about the ABS in general based on previous research, what are its basic components, the importance it enjoys, and its working principle, in addition to the mathematical model. Section III, explain the methodology as the work of the control unit of System ABS and the control algorithm that was applied in this project was explained, while the final section contains the simulation model of the system as the results and finally conclusion.

2. Literature Review

Our study was not the initial endeavor to enhance or improve anti-lock brake systems. Researchers and experts have progressively advanced ABS through the design and implementation of various controllers. This section of our research will examine two prior studies on the same topic conducted by researchers and engineers from various countries, with each study being detailed individually, including its ramifications. Pros or cons Subsequently, we shall elucidate the similarities and distinctions between the aforementioned works and our current undertaking. Yigit Yazicioglu and Y. Samim Unlusoy from Middle East Technical University collaborated on the topic in their correspondence entitled "A Fuzzy Logic Controlled Anti-lock Braking System (ABS) for Enhanced Braking Performance and Directional Stability." A straightforward and efficient fuzzy logic controller is developed for an Anti-Lock Braking System (ABS) to enhance an automobile's braking performance, directional stability during braking, and steering-braking operations on both uniform and non-uniform friction surfaces. The system has two controllers operating concurrently. The initial controller manages longitudinal slip, while the subsequent controller oversees the control of side-slip motion in the vehicle [1-3].

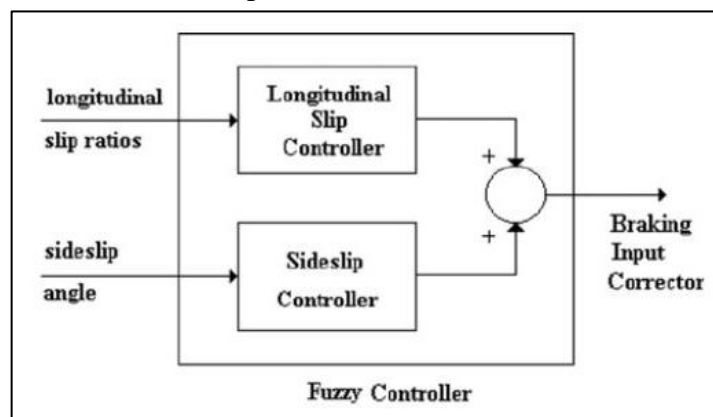


Fig.2. Schematic diagram of the controller.

This study's fuzzy logic controller is developed for a four-wheel nonlinear vehicle model exhibiting nonlinear tire characteristics. Simulations are conducted, and comparisons are drawn between the vehicle model with and without the fuzzy logic-controlled ABS to evaluate controller performance [2-3].

Post-simulation results indicated a 10% disparity in braking distances during straight motion braking, favoring the vehicle equipped with fuzzy logic-controlled ABS. The vehicle's lateral



stability with fuzzy ABS is superior, as none of its wheels are locked or subjected to elevated longitudinal slip ratios, thereby enabling the tires to produce lateral forces. The results demonstrate a significant enhancement in braking and steering simultaneously (B&S) with the implementation of fuzzy ABS. The vehicle equipped with fuzzy ABS halts securely across a reduced distance and is capable of deviating from its original trajectory [2-3].

Hsing-Chung Chen and Andika Wisnujati from Asia University collaborated on the topic in their correspondence entitled "Antilock Braking System (ABS) Based Control Type Regulator Implemented by Neural Network in Various Road Conditions." This study presents a solution to prevent vehicle wheel lock issues, which occur when the friction coefficient between the tire and road surface diminishes upon brake application on slippery surfaces or during emergency braking. The proposed method employs a controller that utilizes an artificial neural network, eliminating the need to learn the inverse dynamics of the controlled system, as is customary in neural control systems.

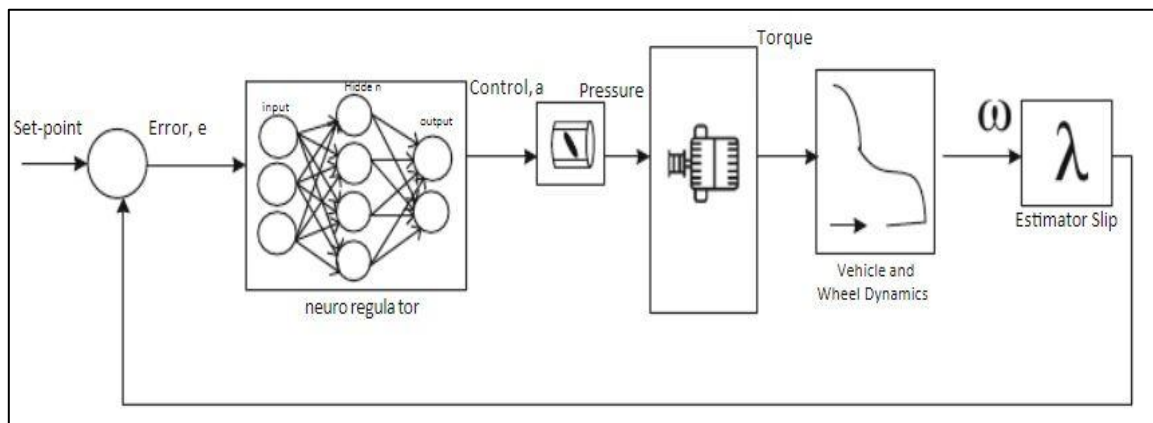


Fig.3. Simplified model closed loop ABS dynamics.

The design approach is based on the premise that the primary goal of control system design is to identify the controller that produces the signal necessary for optimal performance of the plant. Consequently, the training of the neural network requires only a little duration (about 300–500 epochs) to achieve the specified error objective (0.02). The simulation has been implemented and demonstrates strong performance in breaking standards, including maintaining a 20% slip value and achieving the maximum breaking coefficient under varied adverse road circumstances [3]. The neuro-regulator can maintain a 10–30% slipperiness instead. The efficacy of simulation is assessed against the two control methodologies, namely the Bang-bang Controller and Fuzzy Logic Control, under diverse road conditions [3-4].

3. Methodology

3.1 System Description

Anti-lock Braking System is a very vital electromechanical system that greatly improves the safety of the car in harsh conditions by increasing the friction between the tires and the road while maintaining the lateral force, which in turn ensures the possibility of driving the car and reducing the slip rate to reach the lowest possible value [4-5].



3.2 Importance of ABS

ABS is engineered to assist in maintaining vehicle control during emergency braking scenarios. The system detects when one or more wheels lose traction and subsequently modulates the brake pressure to avert wheel lockup. This technology proves advantageous in adverse conditions such as rain, snow, or ice, where wheel grip is compromised. It is particularly effective when decelerating from elevated speeds, thereby minimizing braking distances [4].

3.3 System Modelling

The friction model used in this research is the Burckhardt model as it is particularly suitable for analytical purposes while retaining a good degree of accuracy [4-7].

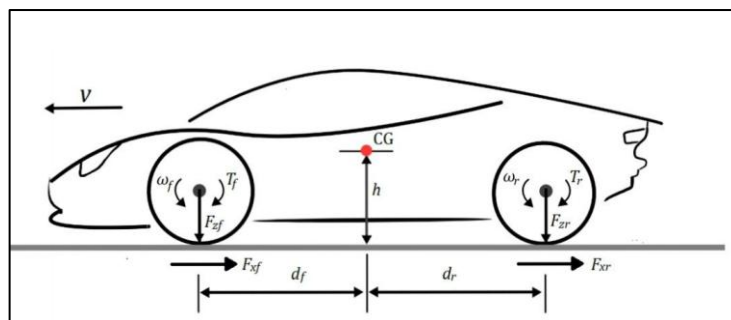


Fig.4. Block diagram of vehicle movement dynamic forces.

The body rotates in a circular path at the angular velocity, which is a change in the angle and linear velocity.

$$v = \omega r \tag{1}$$

v : linear velocity

ω : angular velocity

r : radius

The brake mechanism slows down the wheel by generating a reverse torque that tries to slow down the process with the name T_f front, and T_c rear.

We also have frictional force in cases of sliding. the forces acting on it are only the frictional force which is in the opposite direction and it F_{xr} Back frictional force, F_{xf} Forward frictional force

$$F_{xf} = \mu \cdot F_{zf} \tag{2}$$

F_{xf} : Forward frictional force or Back frictional force

μ : friction coefficient

F_{zf} : force vertical on the surface

The weight of the car is not evenly distributed

Forward frictional force = Back frictional force

The center of gravity is in the center of the car, so the mass force will be distributed

Frictional force for any effect is $F_x = \mu \cdot F_z$.

Since they are both equal, the break will be equal, and therefore the track will be equal



The weight of the cart because there is no other force affected equal $F_z + F_z$.

$$\mathbf{F}_z = \frac{1}{2} \mathbf{mg} \quad (3)$$

m: Mass

g: ground acceleration

Newton's laws are what describe the motion

Newton's laws describe a linear equation.

$$\mathbf{F} = \mathbf{ma} \quad (4)$$

m: Mass

a: linear acceleration

Which relates rotational motion to acceleration is (r)

$$\mathbf{a} = \boldsymbol{\alpha} \cdot \mathbf{r} \quad (5)$$

r: radius

α : Angular acceleration

$$\mathbf{F} = \mathbf{m}\dot{\mathbf{v}} \quad (6)$$

When deriving the first equation $v=r\omega$, we will get

$$\dot{\mathbf{v}} = \mathbf{r}\dot{\boldsymbol{\omega}} \quad (7)$$

We replace it in the F equation.

$$\mathbf{F} = \mathbf{m}\mathbf{r}\dot{\boldsymbol{\omega}} \quad (8)$$

Multiply both sides in (r).

$$\mathbf{r}\mathbf{F} = \mathbf{m}\mathbf{r}^2\dot{\boldsymbol{\omega}}$$

When

$$\mathbf{T} = \mathbf{r}\mathbf{F} \quad (9)$$

$\mathbf{I} = \mathbf{m}\mathbf{r}^2$, **I**: moment of inertia

$$\mathbf{T} = \mathbf{I}\dot{\boldsymbol{\omega}} \quad (10)$$

T=torque: vertical force per radius.

Newton's second law of motion

$$\sum \mathbf{trnqe} = \mathbf{I}\dot{\boldsymbol{\omega}} \quad (11)$$

I: moment

$\dot{\omega}$: Angular acceleration

The laws we found from the above

$$\mathbf{v} = \mathbf{w}\mathbf{r} \rightarrow \dot{\mathbf{v}} = \dot{\mathbf{w}}\mathbf{r}$$

$$\mathbf{F}_x = \boldsymbol{\mu} \cdot \mathbf{F}_z \quad (12)$$

$$\mathbf{F}_z = \frac{1}{2} \mathbf{mg} \quad \therefore \mathbf{F}_z + \mathbf{F}_z = \mathbf{mg}$$

Firstly, we find the dynamic tire

$$\mathbf{I}\dot{\boldsymbol{\omega}} = \mathbf{r}\mathbf{F} - \mathbf{T} \quad , \text{ with } \div \mathbf{I}$$



trnge: The second torque is in the opposite direction

T: Control signal

rF: first trnge

$$\dot{w} = \frac{r}{I} F_x - \frac{T}{I} \quad (13)$$

We find the full dynamic of the car.

$$mv = -2F_x, \text{ with } \div m$$

The sign is negative because it is opposite the direction of motion.

$$\dot{v} = -\frac{2}{m} F_x \quad (14)$$

Fx: constant positive -2/m: Since this part is a constant multiplied by a negative sign, this means that the movement is decreasing. It must always be negative to obtain the stability of the car.

We find the complete sliding dynamics, which I want to control until I get the coefficient of friction, I want.

$$\lambda = \frac{v-rw}{v} \quad (15)$$

In the event of a slip, the forward velocity will not be the same as the back velocity due to the presence of the slip, and therefore λ will not be zero.

Derivation this

$$\lambda = 1 - \frac{r}{v} w$$

$$\dot{\lambda} = -r \frac{vw - w\dot{v}}{v^2} \quad (16)$$

$$\dot{\lambda} = -rv^{-1}\dot{w} + rv^2w\dot{v} \quad (17)$$

$$\dot{\lambda} = -rv^{-1}(rI^{-1}F_x - TI) - 2rv^{-2}wm^{-1}F_x$$

$$\dot{\lambda} = -rv^{-1}I^{-1}F_x + rv^{-1}TI^{-1} - 2rv^{-2}wm^{-1}F_x$$

$$\dot{\lambda} = rv^{-1}I^{-1}(-rF_x + T - 2v^{-1}wm^{-1}F_xI)$$

$$\dot{\lambda} = -2v^{-1}wm^{-1}F_xI - rF_x$$

$$x = rv^{-1}I^{-1} \quad (18)$$

We need to be obtained to this term: $\lambda = 1 - r \frac{w}{v}$

$$\dot{\lambda} = x[-2v^{-1}wm^{-1}F_xI - rF_x + T] \quad (19)$$

We take a common factor to get the desired equation

$$\dot{\lambda} = x[-2\frac{w}{v}m^{-1}F_xmr^2 - rF_x + T]$$

(20)

$$I = mr^2$$

$$\dot{\lambda} = x[r\frac{w}{v}(-2rF_x) - rF_x + T]$$

(21)



When sliding, the rotational speed becomes less than the linear speed

We want to optimize the slip coefficient

We want friction as high as possible to control the movement of the car, but for slippage as little as possible

It is preferable to give breaks intermittently

$$\begin{aligned}\dot{\lambda} &= x \left(-r \frac{w}{v} (2F_x) - rF_x + T \right) \\ \dot{\lambda} &= x \left(-r \frac{w}{v} (2rF_x) + 2rF_x - 2rF_x - rF_x + T \right) \\ \dot{\lambda} &= x(2rF_x \lambda - 3rF_x + T) \quad \therefore \lambda = 1 - \frac{rw}{v} \\ \dot{\lambda} &= (2rF_x x)\lambda + xT - 3rF_x x\end{aligned}\tag{22}$$

We obtained a differential equation in terms of λ .

$2rF_x x$: If this part is negative, this means that the car is stable and heading to zero.

T : This is a controller and it can be **Bu**.

$-3rF_x x$: This is an unwanted part that cannot be zero even if the car is zero because it is a disturbance.

The coefficient of friction is not constant depending on the type of road

$$u(\lambda, \theta) = \theta_1(1 - e^{\lambda\theta_2}) - \lambda\theta_2\tag{23}$$

The function is a curve.

$\theta_1, \theta_2, \theta_3$ are Dependent on the type of road it is a function of λ .

The equation of Error Dynamic as below

$$\begin{aligned}e &= \lambda - ref \\ \dot{e} &= \dot{\lambda} \rightarrow \lambda = e + r \\ \dot{e} &= (2rF_x)e + (2rF_x)r \\ \dot{e} &= (2rF_x)\lambda + xT - (3rF_x x) \\ \dot{e} &= (2rF_x)(e + r) + xu - 3rF_x x \\ \dot{e} &= (2rF_x x)(e + (2rF_x x)r - 3rF_x x + xu)\end{aligned}\tag{24}$$

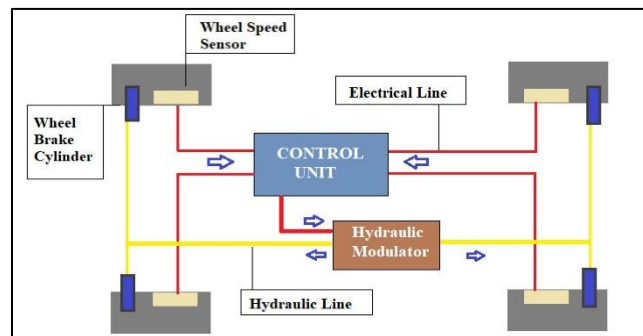
$$\dot{v} = -\mu g$$

$$\dot{\lambda} = \frac{\mu}{v} g \lambda + \left(\frac{1}{mrv} \right) u - \frac{3\mu g}{2v}\tag{25}$$



4. ABS-Control Unit

Anti-lock Braking Systems differ in terms of complexity and their constituent parts depending on the type of vehicle the knee in which the system is used, but cannot be devoid of the most important part Which is the ABS-Control Unit, and since our research is about improving the type of controller to be applied in the system, we must clarify the part that controls the Anti-lock Braking System, ABS-CU is the responsible unit for processing the speed detected by the wheel speed sensors. where the ABS-CU uses signals to control the braking force for each wheel individually. Varying or maintaining the brake pressure [5-6].



The operation of the ABS-CU in modulating or sustaining brake pressure can be elucidated as follows:

ABS-CU computes the velocity and deceleration of each wheel utilizing data from the wheel speed sensors and approximates the vehicle speed at that moment [6].

Depressing the brake pedal elevates the braking fluid pressure in the wheel cylinder, resulting in a reduction of wheel speed. When the disparity between wheel speed and vehicle speed escalates, and wheel deceleration beyond the designated threshold, the Control Unit determines that the wheels are on the verge of locking. Currently, the Control Unit diminishes braking fluid pressure by transmitting a pressure reduction signal to the solenoid valves [6-7].

Upon the commencement of wheel deceleration recovery, the Adaptive Control Unit emits a hold signal to sustain the fluid pressure in the wheel cylinder.

The regulation of brake fluid pressure is achieved through the repetitive escalation and maintenance of pressure [8].

When wheel deceleration surpasses the designated threshold once more, ABS-CU regulates the brake fluid pressure by reiterating the aforementioned procedures.

4.1 Classic PI Control Design

A proportional-integral (PI) controller is a control mechanism that integrates proportional and integral control actions. Consequently, it is designated as a PI controller. The proportional-integral controller employs the control actions of both the proportional and integral components. The integration of these two distinct controllers yields a more efficient system that mitigates the drawbacks inherent to each. The control signal exhibits proportionality to both the error signal and the integral of the error signal [10-11].

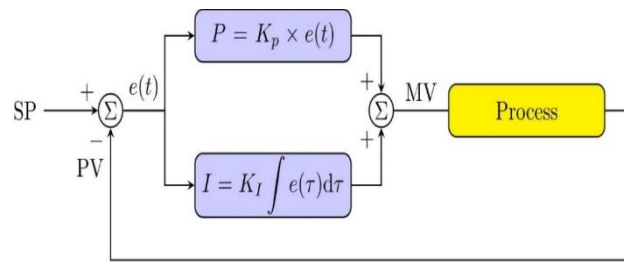


Fig.6. Control system with PI controller.

The mathematical representation of the proportional plus integral controller is given as:

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt \quad (26)$$

$$\therefore e(t) = \lambda_{\text{optimal}} - \lambda$$

Where:

K_p : Proportional gain

K_i : Integral gain

e : Error

The general equation for the PI-Controller consists of only two parts, the first is relative and the other is integrative, each of which has a response and behavior that affects differently from the other on the overall response of the controller follow as:

The proportional component relies solely on the disparity between the set point and the process variable [10]. This discrepancy is termed the Error term. The proportional gain (K_p) establishes the ratio between the output response and the error signal. If the error term measures 10, a proportional gain of 5 would yield a proportional response of 50. Generally, augmenting the proportional gain will enhance the velocity of the control system's response. Nonetheless, if the proportionate gain is excessively high, the process variable will commence oscillation. Should K_p be augmented more, the oscillations will intensify, rendering the system unstable and perhaps leading to uncontrollable oscillations [10-13].

The integral component aggregates the error term over time. The outcome is that even a minor error term will lead to a gradual increase in the integral component. The integral response will consistently rise over time unless the error is null, hence driving the Steady-State error to zero. The steady-state error is the ultimate discrepancy between the process variable and the set point. Integral windup occurs when the integral action saturates a controller while failing to reduce the error signal to zero [15-16].

We used the MATLAB language for system simulation to process the close loop system, which consists of equation 2 for the process and 3 for the control. For modeling, simulating, and analyzing multi-domain dynamic systems, and it allows you to incorporate MATLAB programming codes



into models through User-Defined functions / MATLAB function. Our model consists of two MATLAB functions, the first works on applying the mathematical equations of the system through the code shown below.

```
function [vdot, edot] = fcn (u, e, ref, v)
%#codegen
r = 0.31;
m = 900;
I = m*r*r;
x = r/(v*I);
limda = e+ref;
th1=1.2801;
th2=23.990;
th3=0.52;
meu = th1*(1-exp(-limda*th2)) -(limda*th3);
fx = meu*(0.5) *m*9.81;
edot = (2*r*fx*x*e) +(2*r*fx*x*ref) -(3*r*fx*x) + (x*u);
vdot = (-2/m) *fx;
```

This function receives four values as inputs, namely the controller, error, reference, and linear speed, through which it calculates each of the \dot{v} and \dot{e} as outputs.

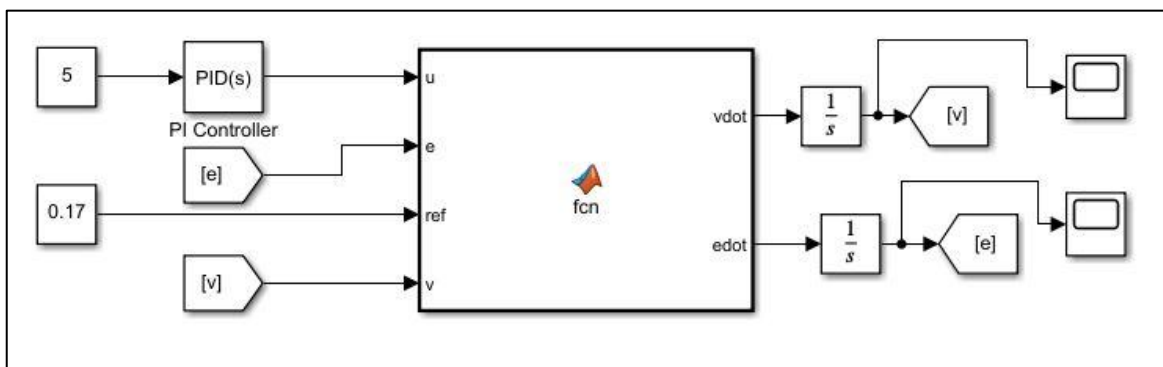


Fig.7. Block diagram of the system simulation model.

In the simulation model of the system, the controller is applied that is built on the system equations to get a result represented by \dot{e} , \dot{v} , which is integrated and then displayed on the screen in the form of waves, also after their integration they are assigned again as values for each of the e , v .

After simulating the first function of the equation of the system and the controller, we found the behavior followed by the variables of the system and the controller itself with the change with time. where the slip rate takes the form of the curve shown in Figure 8, and increases gradually with the passage of time until 0.2, then decreases to settle at approximately 0.175, representing the reference value.

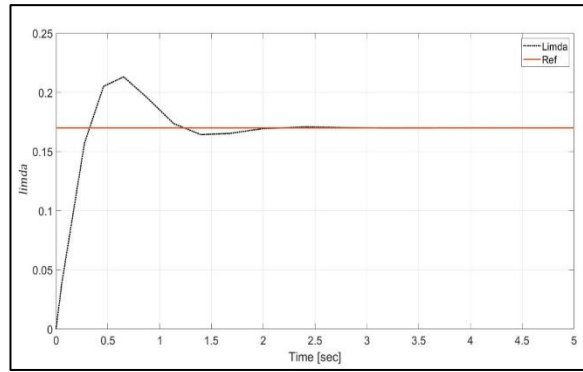


Fig.8. The curve of change in the slip rate with to time

As well, we found the controller's response that represents the behavior that the controller follows to ensure that the system remains in a safe state, by which we mean that the brakes are not locked, and thus the vehicle not slips and go out of control, and that can be represented in figure 9.

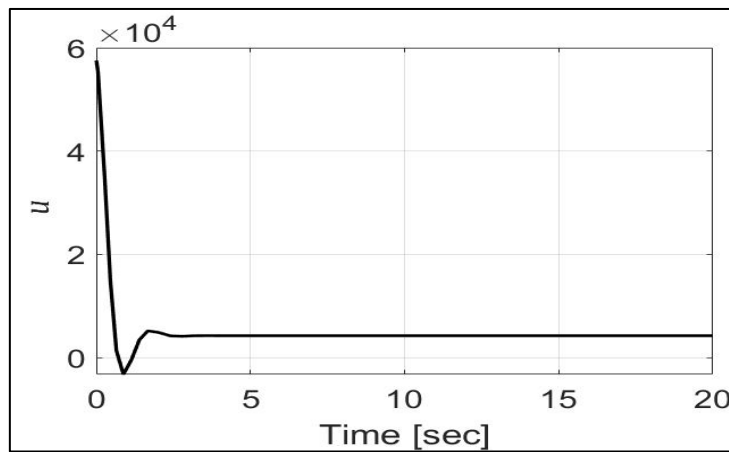


Fig. 9. The response of the controller.

In addition to the velocity of the vehicle, which is represented in the curve shown in Figure 10, where after applying the controller to the braking system, which made the speed decreased from 250 m/s t to 20 m/s .

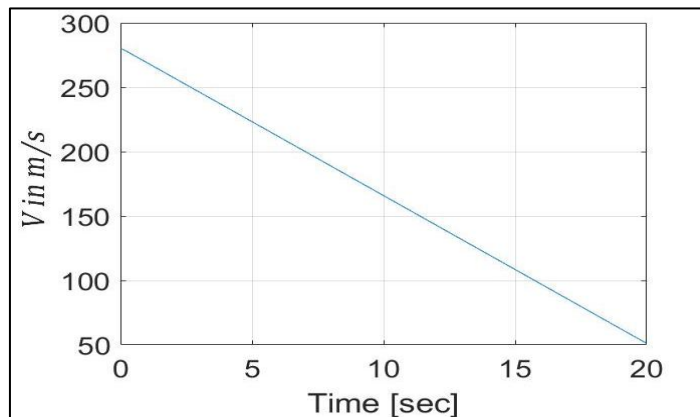


Fig .10. The curve of change in the velocity with to time



From the results mentioned above, we notice that the slip rate λ started from zero. This is expected because before pressing the brake, the linear clock is equal to the rotational speed before the break, the slip was zero, and the response was very fast, and the system settled at the best point in less than a minute.

If we assume that the car is driving on a dry road, and after three seconds it will enter a wet road. When this transition occurs, the control did not receive the sudden change, so it remained in the old state, and this is considered a problem that we will treat and solve it. when simulation this case the behavior of the variables will be represented as follows:

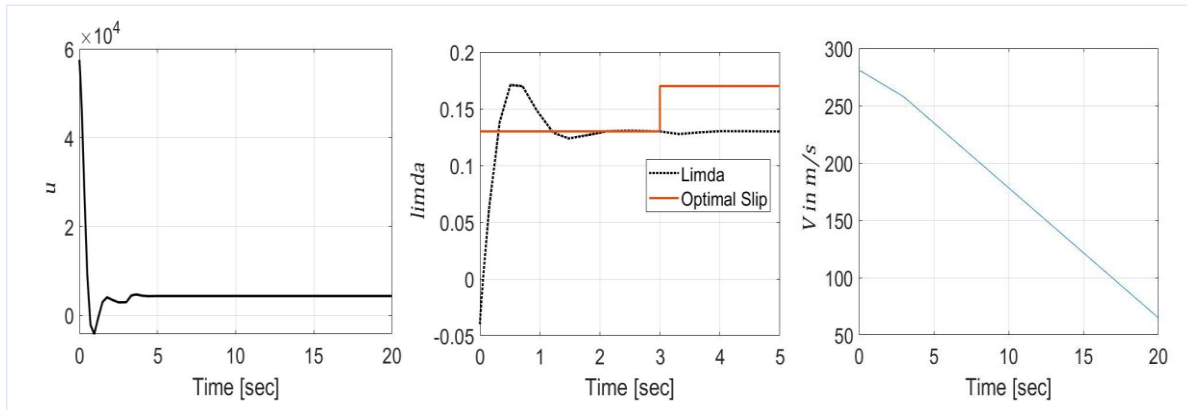


Fig .11. The behaviour of the variables in case two.

4.2 Extra Adaptive Control

Extremism Seeking (ES) is a robust real-time optimization method employed to optimize a function with an unknown analytical form, relying solely on the available output (performance measure), applicable when either the system or the cost function remains unidentified [17 – 18]. The application of extreme seeking in real-time optimization originated in 1922 with Leblanc's article, although stability proofs were not introduced until the late 1990s. Currently, there is an increasing interest in this domain. Multiple methodologies for extremum seeking are available. This methodology was founded on sliding mode principles, a robust nonlinear control technique extensively utilized in observation and control [18-20].

By applying the adaptive control on the system and simulating that using the MATLAB environment, we were able to address the problem of the sudden change in the nature of the road on which the vehicle is traveling and the controller's lack of response to that, as noted in the previous results, and thus we got the optimal results as shown below.

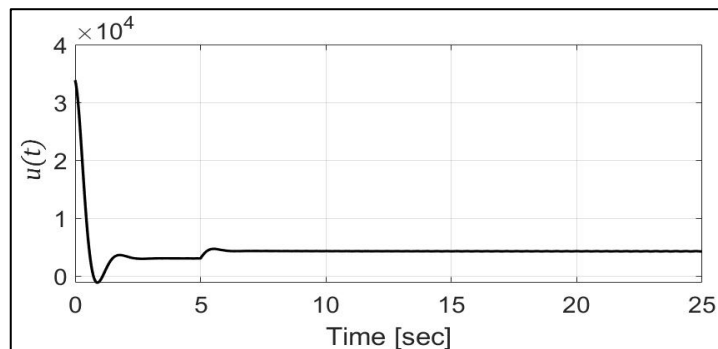


Fig.12. Response of the controller in final result



As shown in figure 13, the response of the controller undergoes a change twice to be in two forms, each of which corresponds to the different case in the first when the road is dry and the other when it is wet, and this is a required where making the controller adapt to the situation that the system is going through.

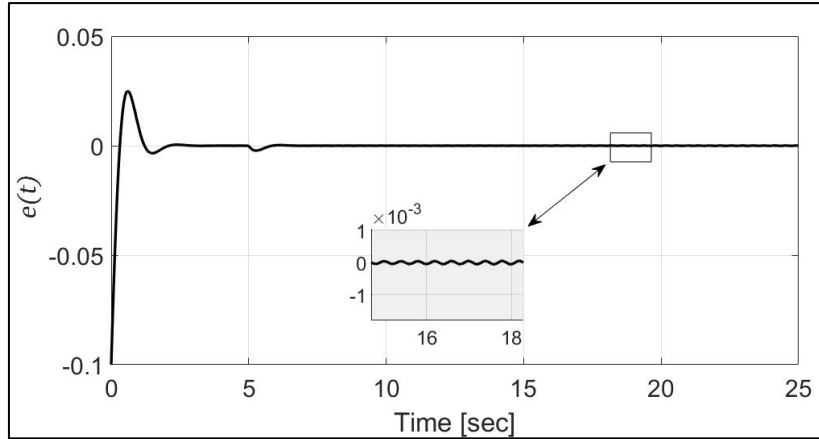


Fig.13. The Error of the System.

And the speed response of the controller, which makes the error since the operation of the system go towards zero, with a time estimated at approximately one second, In the long run, it maintains the same fluctuation rate around zero with a very small value that can hardly be calculated and can be considered ideal and identical to zero [11 – 13].

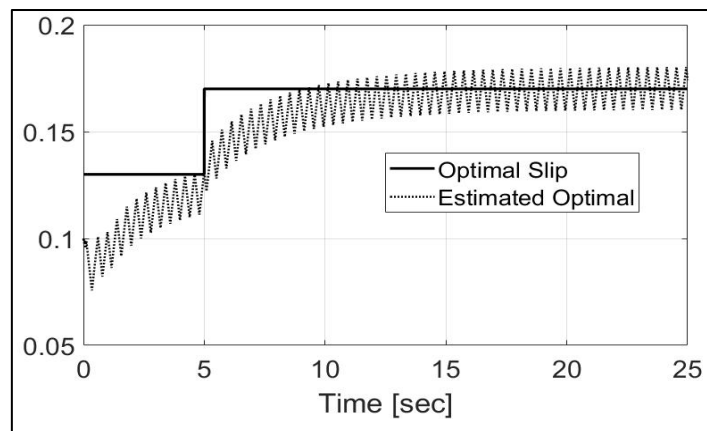


Fig.14. Optimal slip coefficient and Estimated.

Figure 15 shows both the ideal slip coefficient for our system and the slip coefficient achieved by implementing the adaptive controller, and how it oscillates around its ideal value.

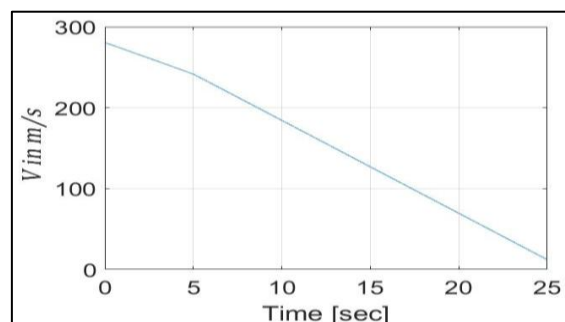


Fig.15. The curve of change in velocity in the final result



Figure 16 contains a curve that shows the possibility of applying an adaptive controller to a system based on the principle of intermittent braking to reduce the vehicle speed from 300 to almost zero in a period of time of about 25 seconds only. All of this is a good result and shows the extent of our success in improving the slip coefficient, which is the main factor that the ABS joiners are trying to make as much as possible within the acceptable range, which provides high safety.

5. Conclusion

The advancement of technology in automobiles is leading to increasingly sophisticated braking systems. Antilock brakes enhance a driver's control of a vehicle under certain road conditions that necessitate abrupt braking. In vehicles lacking antilock braking systems, drivers must pump the brakes in slippery circumstances to prevent wheel lock-up and loss of control. ABS synchronizes wheel activity with a sensor on each wheel that modulates braking pressure as needed, ensuring all wheels operate within a comparable speed range. This research elucidates the significance of these systems and constructs a model of the ABS using an adaptive PI controller. Utilizing the Burckhardt model of frictional dynamics, this study simulates the model in MATLAB-Simulink to observe the system's behavior and the enhancements afforded by the use of the adaptive PI controller module. By simulating the system and obtaining results for more than one case, the adaptive controller we designed demonstrated. Its merit in improving the performance of ABS systems, As the control unit has been applied to different road conditions and sudden change. Thus, we obtained a slip coefficient ranging around (0.17) and a high response speed that Provides the ability to stop a moving trolley at 300 m/s speeds in a very short period of time, about 25 seconds. Finally, this research provides a complete study through which an adaptive control unit can be established on the ground, enabled by using the results obtained through our simulations of the system and benefiting from them in the design to develop a control unit and test it on different vehicles because it has the ability to improve performance of ABS Systems.

References

1. A. Aly, E. Zeidan, A. Hamed, and F. Salem, "An Antilock-Braking Systems (ABS) Control : A Technical Review," *Intell. Control Autom.*, no. 2, pp. 186–195, 2011, DOI: 10.4236/ica.2011.23023.
2. S. John and J. O. Pedro, "Hybrid Feedback Linearization Slip Control for Anti-lock Braking System," *Acta Polytech. Hungarica*, vol. 10, no. 1, pp. 81–99, 2013, DOI:10.12700/aph.10.01.2013.1.5.
3. Y. Yazicioglu and Y. Samim Unlusoy, "A fuzzy logic controlled Anti-lock Braking System (ABS) for improved braking performance and directional stability," *Int. J. Veh. Des.*, vol. 48, no. 3–4, pp. 299–315, 2008, DOI: 10.1504/IJVD.2008.022581.
4. K. J. Astrom, T. Hagglund, C. C. Hang, and W. K. Ho, Automatic tuning and adaptation for PID controllers - A survey, *Control Eng.Practice*, vol. 1(Issue 4): 699-714, 1993, doi.org/10.1016/0967-0661(93)91394-C
5. D. G. V and A. C. Ramachandra, "Slip Ratio Control of Anti-Lock Braking System with Bang-Bang Controller Abstract ;," *Int. J. Comput. Tech.*, vol. 4, no. 1, pp. 97–104, 2017.



6. M. MONTANI, D. VITALITI, R. CAPITANI and C. ANNICCHIARICO, Performance review of three car integrated ABS types: Development of a tire independent wheel speed control, *Energies* 13(23), paper 6183, 2020, doi.org/10.3390/en13236183.
7. C. XU, K. CHENG, L. SHA, W. TING and K. DING, Simulation of the integrated controller of the anti-lock braking system, *Proceedings of 2009 3rd International Conference on Power Electronics Systems and Applications*, Hong Kong, China, pp. 1–3, 2009.
8. R. Matušů, B. Şenol and L. Pekař, Robust PI Control of Interval Plants With Gain and Phase Margin Specifications: Application to a Continuous Stirred Tank Reactor, in *IEEE Access*, vol. 8: 145372-145380, 2020. DOI: 10.1109/ACCESS.2020.3014684
9. A. E.-N. S. Ahmed, A. S. Ali, N. M. Ghazaly, and G. T. Abd el-Jaber, “PID controller of active suspension system for a quarter car model,” *Int. J. Adv. Eng. Technol.*, vol. 8, no. 6, pp. 899–909, 2015. DOI: <https://doi.org/10.54644/jte.68.2022.1126>.
10. M. Shouran ,E. Elgamli, Teaching-Learning based Optimization Algorithm Tuned Fuzzy-PID Controller for Continuous Stirred Tank Reactor, *International Research Journal of Engineering and Technology (IRJET)*, vol. 7(Issue 9): 3882– 3886, 2020.
11. A. Almabrok, M. Psarakis and A. Dounis, Fast Tuning of the PID Controller in An HVAC System Using the Big Bang–Big Crunch Algorithm and FPGA Technology, *Journal of Algorithms*, Vol. 10(Issue 11): 146, 2018.
12. Nikhil Subhash Shewale, R. Deivanathan, Modelling and Simulation of Anti-lock Braking System, *International Journal of Engineering and Technical Research (IJETR)*, ISSN: 2321-0869 Volume-7, Issue-1, January 2017
13. Prashant Shah, Shacheendra Kishor Labh, Surya Prasad Adhikari, Study on Performance of Vehicle Anti-lock Braking System with Fuzzy Logic controller in Matlab/Simulink, *International Journal of Scientific Research and Engineering Development-- Volume 3 - Issue 4*, July - Aug 2020.
14. Shady Abd El-Fatah, Abdel-Nasser Sharkawy, Ahmad Moaaz, Nouby Ghazaly, A Comparative Study of Different Control Methods for Anti-Lock Braking System (ABS), *SVU-International Journal of Engineering Sciences and Applications* (2021) 2(1): 27-34, Print ISSN 2785-9967|, DOI 0.21608/svusrc.2021.65855.1007.
15. K.B. Ariyur, and M. Krstic, *Real-time Optimization by Extremum seeking Control* (Wiley-Interscience, Hoboken, 2003) DOI:10.1002/0471669784.
16. N. Killingsworth and M. Krstic, Auto-tuning of PID controllers via extremum seeking, *Proceedings of the 2005 American Control Conference*, 2005, DOI: 10.1109/ACC.2005.1470304.
17. Q. Chen, Y. Tan, J. Li and I. Mareels, Decentralized PID Control Design for Magnetic Levitation Systems Using Extremum Seeking, *IEEE Access*, vol. 6: 3059-3067, 2018, DOI: 10.1109/ACCESS.2017.2787052.
18. T. Roux-Oliveira, L.R. Costa, & A.V. Pino, and P. Paz, Extremum Seeking-based Adaptive PID Control applied to Neuromuscular Electrical Stimulation. *An. Acad. Bras. Ciênc.*, vol. 91(Suppl. 1), 2019, doi.org/10.1590/0001-3765201820180544.
19. Y. B. Salamah and Ü. Özgüner, Sliding Mode Multivariable Extremum Seeking Control with Application to Wind Farm Power Optimization, *2018 Annual American Control Conference (ACC)*, Milwaukee, WI, pp. 5321-5326, 2018.



20. S. M. Raafat and R. Hussein, Multivariable Extremum Seeking Control for Power Maximization and PI Tuning of Wind Turbine System, 2018 Third Scientific Conference of Electrical Engineering (SCEE), pp. 128-133, Baghdad, Iraq, 2018, DOI: 10.1109/SCEE.2018.8684099.