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A REVIEW OF THE ANTI-LOCK BRAKE DIAGNOSIS SYSTEM AND ITS CONTROL TECHNIQUES

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ABSTRACT
The brake system is one of the important systems in vehicles because of its importance in stopping the car in the shortest stopping distance. Some appropriate systems help the brake system work to reduce the stopping distance. These systems include an anti-lock brake system. The Anti-Lock Braking System (ABS) is one of the most important safety features in modern vehicles because it helps the driver control his vehicle and stability. It is a device integrating complicated electronic systems, hydraulic systems, and mechanical components, as it prevents the wheels from locking up when applying the brake, which reduces the braking time and stops distance. It is possible to produce faults in these systems due to extreme vehicle operating conditions, which may lead to the failure of the ABS and stop operating. In this paper, much previous research which discussed the different types of faults, control techniques used in this system, and the components of these systems.

KEYWORDS
Anti-lock braking system, fuzzy logic control, PID control, angular speed sensor.

INTRODUCTION
An anti-lock braking system (ABS) is a safe anti-skidding braking system used on vehicles, ABS operates by preventing the wheels from locking up during braking, thereby maintaining tractive contact with the road surface and allowing the driver to maintain more control over the vehicle. Since the development of the first motor-driven vehicle in 1769 and the occurrence of the first driving accident in 1770, engineers were determined to reduce driving accidents and improve the safety of vehicles, [1], so car security system can be divided into two main parts: one is the active security systems; the other is the passive security system. An anti-lock braking system (ABS) is an important active security system, and it is used in advanced automobiles to prevent slip and locking up of wheel after hard brake applied. Its response time is very faster so that makes it easy steering for the driver. ABS generally offer advanced vehicle control and minimize the stopping distance in the slippery and dry surface. The ABS modulates the brake line pressure independent of the pedal

force to bring the wheel speed back to the slip level range that necessary to the optimal braking performance. The brain of the antilock braking system consists of an Electronic Control Unit (ECU), a wheel speed sensor, and a hydraulic modulator. ABS is a closed circuit; hence it used the feedback control system that modulates the brake pressure in response to the wheel deceleration and wheel angular velocity to prevent the controlled wheel from locking. Importance of Antilock Braking Systems reduce stopping distances, improve stability, and improve steerability during braking.

Types of Anti-lock braking system

1- **Four-Channel, Four Sensor ABS.**
2- **Three Channel, Four Sensor ABS.**
3- **Three Channel, Three Sensor ABS.**
4- **Two Channel, Four Sensor ABS.**
5- **One Channel, One Sensor ABS.**

The Anti-lock Brake Diagnosis System and Its Control Techniques

Ali H. Elshanti, [2] has displayed Model-based Fault Detection and Diagnosis of the Anti-lock Braking System, he discussed multi faults which occur in ABS and used a non-linear mathematical model of the ABS is developed and ABS is modeled using Simulink and some of the events are displayed which demonstrate the potential of the proposed model-based portent approach. The model-based strategy is also used in the ABS fault prediction and prognostics. Some prognostics and faults prediction such as pump efficiency loss, fluid leakage, brake pad efficiency loss, and air blister in brake fluid are discussed.

Jeonghoon Song, [3] has presented a study on an anti-lock braking system controller and rear-wheel controller to enhance vehicle lateral stability. He used a mathematical vehicle model that is designed to analyze and improve the dynamic performance of a vehicle, also used technique to control an anti-lock braking system and rear-wheel which a sliding mode controller and a proportional–integral– derivative (PID) controller for rear-wheel steering, to enhance the stability, steerability, and drivability of the vehicle during transient maneuvers. The braking and steering performances of controllers are evaluated for various driving conditions, such as straight and J-turn maneuvers. simulation results show that the proposed full car model is sufficient to predict vehicle responses accurately and it also demonstrated that the use of a rear-wheel controller as a yaw motion controller can increase its lateral stability and reduced the slip angle at high speeds.

Wei Zhan, [4], has presented Noise and Vibration Modeling for Anti-Lock Brake Systems, he proposed a new methodology for noise and vibration analysis for Anti-Lock Brake Systems (ABS), this methodology depends on a correlation between noise and vibration measurement data and simulation results need to be established. A comprehensive ABS model is derived for noise and vibration study. This model can be set up to do different types of simulations for noise and vibration analysis, also model can be set up do different types of simulations for noise and vibration analysis,

the model can greatly reduce the time to market for ABS products. It also makes system-level optimization possible.

Sahil Jitesh, [5], has presented Antilock Braking System (ABS). He explained the importance of the ABS and the main components of this system, also presented the main components of An antilock braking system which consist of an Electronic Control Unit (ECU), wheel speed sensor and hydraulic modulator, speed sensor measure the angular speed of the wheel, on the other hand, the control of angular speed by using a hydraulic modulator which it control of by Electronic Control Unit (ECU). Therefore, ABS is a closed circuit, hence it used the feedback control system that modulates the brake pressure in response to the wheel deceleration and wheel angular velocity to prevent the controlled wheel from locking.

Sharkawy, [6], studied the performance of ABS with a variation of weight, friction coefficient of road, road inclination, etc. A self-tuning PID control scheme to overcome these effects via fuzzy GA is developed; with a control, objective to minimize stopping distance while keeping the slip ratio of the tires within the desired range.

M.P. Cabasino, [7], presented fault diagnosis of an ABS using Petri nets, he displayed an X-by-Wire system which used in automotive is a system controlled through a communication channel "By wire" denotes a control system that replaces traditional hydraulic or mechanical linkage with electronic connections between control units that drive electromechanical actuators. Furthermore, an X-by-Wire system is also called a dry system, as the hydraulic is no longer necessary. He focused on a Brake-by-Wire system combined with a high-level brake function: the Anti-lock Braking System (ABS), In modern cars the whole system is composed of four different ABS, one for each wheel, that work locally and independently. He provided a description, in terms of a finite state machine, of the brake system of a wheel. Then, he focused on the ABS and its interaction with the wheel in braking conditions and proposed a Petri net (PN) model of its behavior. He also keeps into account the reliability of the sensor that is responsible for the activation of the ABS, then he discussed how such a PN model can be used to perform fault diagnosis and diagnosable analysis using the PN based approaches.

V. Goga, [8], has presented the Mechatronic Model of Anti-lock Braking System (ABS), also proposed a newly designed quarter-model which describes the vehicle braking process and dynamics. This model is based around the main scheme with ABS that can be fully modified for various adhesive conditions to simulate and further optimize the functionality of the ABS. He provided several simulations on different models of surfaces with activated and deactivated ABS and he modeled friction coefficient for these four surfaces: dry asphalt (dark blue), wet asphalt (green), packed snow (red), and ice (light blue). His results showed, there is a significant difference between braking with ABS turned ON and OFF. With an activated ABS control unit, the pressure in brakes decreases avoiding tire locking, relative slip varies between 20 – 30 % and the friction coefficient between the tire and surface is almost

at its maximum. When the ABS is deactivated, the tire becomes locked, relative slip increases rapidly to 100 %, the friction coefficient is smaller and the effect of braking far from optimal. The stopping distance with activated ABS is shorter by about one meter.

Ayman A. Aly, [9], has displayed An Antilock-Braking Systems (ABS) Control: A Technical Review. He reviewed the methods used in the design of ABS systems, and the components of ABS which consist of the vehicle's physical brakes, wheel speed sensors (up to 4), an electronic control unit (ECU), brake master cylinder, a hydraulic modulator unit with pump and valves. Some of the advanced ABS systems include an accelerometer to determine the deceleration of the vehicle. He displayed multi techniques control used in ABS such as Classical Control Methods Based on PID Control, Optimal Control Methods Based on Lyapunov approach, Nonlinear Control Based on Backstepping Control Design, Robust Control Based on Sliding Mode Control Method, Adaptive Control Based on Gain Scheduling Control Method and Intelligent Control Based on Fuzzy Logic.

Pours mad, [10], proposed an adaptive NN-based hybrid controller for ABS. The hybrid controller is based on the well-known feedback linearization, combined with two feedforward neural networks that are proposed to learn the nonlinearities of the antilock braking system associated with the feedback linearization controller. The stability of the proposed hybrid controller is studied using the Lyapunov stability theory. The simulation results showed that the effectiveness of the proposed controller and its superiority over the standard feedback linearization controller, also reveal that the proposed controller can achieve desirable performance under transition between various road conditions.

Zhang Wen-xia, [11], has presented the application of neural network in fault diagnosis of an Anti-lock braking system. He introduced the method about the behavior pattern recognition and diagnosis when actuator and sensor of automobile ABS fail. He showed the structure and components of ABS, which consists of wheel velocity sensor, braking pressure regulating device, electronic control device, and ABS warning lights, then he used BP (The backpropagation neural network) to recognize and diagnose the behavior pattern when the automobile ABS broke down, to solve this problem. The application of BP neural network in fault diagnosis of ABS can improve the safety performance of cars.

Chankit Jain, [12], has proposed Linear Control Technique for Anti-Lock Braking System, he explained dynamic system equations and he expressed a slip ratio in terms of system variables namely vehicle linear velocity and angular velocity of the wheel. Then, applied a bias braking force system, the response is obtained using Simulink models. On the other hand, he tested the linear control strategies like PI-type the effectiveness of maintaining the desired slip ratio. Therefore, It observed that a steady-state error of 10% occurring in all the control system models.

Vu Trieu Minh, [13], have presented the development of Anti-lock Braking System (ABS) for Vehicles Braking. He developed a real laboratory of the anti-lock braking system (ABS) for vehicle and conducted real experiments to verify the ability of this ABS to prevent the vehicle wheel from being locked while braking, Two method controllers have been used it are PID and fuzzy logic to test for analysis and comparison. This ABS laboratory has been designed to simulate and analyze the performances of ABS with different control techniques on various roads and load conditions. Results showed the use of the Fuzzy controller exhibited better and superior performances than the PID control to control ABS.

Patil and Longoria, [14], described the design and hardware-in-the-loop implementation of an ABS control for a one-fifth scale vehicle. The ABS controller organized into two functional modules: a sliding mode controller that generates the desired brake torque to be applied based on the vehicle and the wheel dynamics, and a compensator for the brake actuation system to enable it to track a reference torque. . By implementing the wheel and vehicle dynamics, and the wheel-road surface interaction in software along with the two controllers, the antilock braking performance of the actuator and the control algorithm can be evaluated for emergency braking on a variety of road surfaces and driving conditions quickly, without any changes to the test setup. Hardware-in-the-loop test results in two panic braking scenarios are presented, braking in straight-line with surface change and braking while turning. The results showed that the ABS controller is unable to perfectly regulate the wheel slip at the desired value because of the 'bang-bang' type operation (caused by the limited brake actuator bandwidth), the test results validate the modular design of the ABS control and its hardware-in-the-loop implementation.

Luo Xiao, [15], has described the Modeling and Simulation of Anti-lock Braking System based on Fuzzy Control, he used Matlab/Simulink software to an implemented simulation of an anti-lock braking system, as well as modeling and control of the ABS. Taking into account the simplified design, and the higher requirements of real-time control, therefore, he chooses a single wheel model to build the simulation system. The simulation results indicated that, among several methods of controlling a vehicle's anti-lock braking system, the method of using the fuzzy control door limit control strategy can make the simulation results more accurate.

Wietsche Clement William, [16], has proposed the test and simulation of ABS on rough, non-deformable terrains, he has modified a version of the Bosch ABS algorithm is implemented in Matlab/Simulink using co-simulation with a validated full vehicle ADAMS model that incorporates a valid high-fidelity FTire model. A non-ABS test vehicle has been fitted with a commercial ABS modulator controlled by an embedded computer. The co-simulation model has been validated with vehicle test data on both smooth and rough terrains. The results showed that wheel speed fluctuations on rough terrain cause inaccuracies in the estimation of vehicle velocity and excessive noise on the derived rotational acceleration values, which leads to inaccurate longitudinal slip calculation and poor control state decisions. He has concluded that, although the correlation is not yet as desired, the combined use of a

simulation model and test vehicle can be a useful tool in the research of ABS braking on rough terrains.

Pradeep Rohilla, [17], have presented the design and Analysis of Controller for Antilock Braking System in Matlab/Simulation. He produced a scientific model of electronically monitored slowing mechanism (ABS) of a quarter auto model. He executed the different sorts of controllers such as P, PI, PD, and PID, and results are analyzed in Matlab/Simulink environment. A Genetic algorithmic optimization technique has been used to obtain gain parameters of controllers. An ABS has been compared with and without the controller and further between the distinctive sorts of controllers, the results showed the output response of a PID controller is better as compared to different controllers.

Mohammad Najeh Nemah, [18], has described the Modelling and Development of Linear and Nonlinear Intelligent Controllers for Anti-lock Braking Systems (ABS). He proposed design and mathematical modeling of the nonlinear dynamic model of the antilock braking system and derived it relying upon its physical system by using Matlab/Simulink program. He proposed two different controllers technique to control the behaviors of ABS, the first technique PID controller with linearized technique around a specific point to control the nonlinear system, while the second one used the nonlinear discrete-time controller to control the nonlinear mathematical model directly. The simulation results showed, this investigation contributes to more additional information for the simulation of the two controllers and demonstrates a clear and reasonable advantage of the classical PID controller on the nonlinear discrete-time controller in control of the antilock braking system.

A. Manivanna Boopathi, [19], presented Design of Grey-Verhulst Sliding Mode Controller for Antilock Braking System, he proposed an adaptive controller called Grey- Verhulst Sliding Mode Controller (GVSMC) for the Inteco laboratory ABS quarter car model. The Grey-Verhulst Model (GVM) predicts the wheel velocity and thereby the wheel slip. The error input to the controller is calculated by comparing the actual and predicted wheel slips with the desired slip. The simulation results showed that the performance of the proposed GVSMC is better than the simple SMC and Grey SMC and the proposed controller also reduces the stopping distance considerably.

Dankan Gowda V., [20], presented Slip Ratio Control of Anti-Lock Braking System with Bang-Bang Controller. He proposed a mathematical model of ABS with Bang-Bang control algorithm have been implemented in Simulink and he extensive simulation studies is also performed to verify the effectiveness of the controller. He compared between the performance of vehicle braking with and without Bang-Bang controller and analyzed it. Braking with Bang-Bang Controller mode the wheel speed and the vehicle speed are set down at the same time and the slip distance, speed, and relative slip of the vehicle is founded. The simulation results showed that concluded that the Bang-Bang Controller has better braking performance because the wheel

speed and the vehicle speed is been controlled at the same time to avoid the vehicle to skid during the panic braking.

Huang and Shih, [21], have used the fuzzy controller to control the hydraulic modulator and hence the brake pressure. The performance of the controller and hydraulic modulator are assessed by the hardware in loop (HIL) experiments. The HIL simulation results showed that the hydraulic modulator and controller can keep the slip ratio at 0.2 with different initial braking velocities or under different adhesive coefficients.

Ruru Hao, [22], has proposed Modelling for ABS Bench Detection Method, he presented. The bench detection system for the ABS. The bench detection system mainly consists of a road adhesion coefficient simulation unit, auto motion inertia simulation unit, measurement & control system, and data acquisition system. The simulation results showed that the characteristic of the simulation curves is consistent with the ABS braking curves, which indicates the feasibility of the bench detection principle.

Eze Paulinus C., [23], presented Linear Slip Control for Improved Antilock Braking System, he has presented linear slip control for the improved antilock braking system. Therefore, he designed and simulated a slip control system with improved tracking performance in a Matlab/Simulink environment, and thereby maintaining an optimal wheel slip ratio. He developed a two degree of freedom proportional plus integral plus derivative (2DOFPID) controller and integrated it into a dynamic model of a quarter-car, the quarter car and the actuator have been modeled in continuous time, while the controller is implemented in discrete time. The simulation results showed that the braking performance of the assisted antilock braking system was significantly improved, the braking time reduced, and the stopping distance reduced consequently.

Qi Chen, [24], has proposed Model-Based Fault Diagnosis of an Anti-Lock Braking System via Structural Analysis. He employed a model-based methodology with respect to structural analysis to achieve an efficient fault detection and identification (FDI) system design and monitor the functions of ABS to avoid any malfunction. Fault diagnosis for ABS based on SA has been performed, where the methodology of SA is proved again to be an effective way to assess the fault detectability and design of the FDI system. The analysis involves five essential steps of SA applied to ABS, which includes critical faults analysis, fault modelling, fault detectability analysis and fault isolability analysis, Minimal Structural Over-determined (MSO) sets selection, and MSO-based residual design. The results generated by numerical simulations showed that the proposed FDI system can detect and isolate all the injected faults, which is consistent with the theoretical analysis by SA, and also eventually validated by experimental testing on the vehicle (EcoCAR2) ABS.

Onitet al., [25], have proposed a novel strategy for the design of sliding mode controller (SMC). As the velocity of the vehicle changes, the optimum value of the

wheel slip will also alter. Gray predictor is employed to anticipate the future output of the system. Khalid M. Algadah, [26], has described Anti-Lock Braking System Components Modelling. He modeled and simulated the system by using many different simulation software, to simulated and visualize the system. He used equations for system components were gathered, to control the system, also he applied some control strategies such as Adaptive fuzzy logic, PID control, etc. The stopping distance, wheel slip ratio, brake torque, and wheel speed have been simulated and displayed statistical analysis of the software used for the simulation. The results showed modeling and simulation of the system would give a better comprehension of how the system works and could be very helpful in system development and will help to obtain an ideal braking performance and safer driving.

Majid Mokarram, [27], has proposed A fuzzy Anti-lock braking system (ABS) controller using CMOS circuits. He designs an optimized fuzzy logic controller to improve the performance of an Anti-lock braking system (ABS). Then he simulated and training the ABS function in MATLAB. The FLC has been designed in a 0.35 µm standard CMOS process, this design of the circuit makes it has high speed and low power consumption. The function and performance of the design using HSPICE simulations of the circuits have been demonstrated. Simulation results showed a very satisfying performance of the controller circuit. It was shown that in the case of the optimal fuzzy controller, the slip is kept at a minimum value. Also, the oscillations are much less than that of the fuzzy logic and PI controller, so the vehicle has good lateral stability and good steerability.

Angel Paleta Blancas, [28], has presented a Simulation of the ABS Braking System Behavior in Critical Faults. He used a mathematical model ABS modeling in MATLAB/Simulink, which simulates the dynamics of a car during rough braking with abnormal system operation, he compared the system with normal operation and proposed 5 scenarios were a fault in the hydraulic actuator, fault in the ECU, that is, deviation in the system, fault in the vehicle speed sensor and fault in the tire speed sensor. The simulation results showed that there are differences in the value of the braking time and the braking distance when the comparison between with normal system operation and proposed 5 scenarios, where the braking distance and braking time have increased.

N. Vivekanandan, [29], has described Experimental Validation of Fuzzy Logic Based Anti-Lock Braking System Used in Quarter Car Model He presented the use of Fuzzy Logic in the development of ABS to enhance the control over braking. MATLAB SIMULINK environment has been used to structure the mathematical model to develop a program of fuzzy logic that interfaced with an experimental setup consisting of ABS implemented in a quarter car model. The results showed that fuzzy based ABS control improves the braking performance, and the convincing advantage of fuzzy logic is the ability to modify and tune certain parts of this characteristic surface easily and carefully. While soft computing methods like Fuzzy control does not need a precise model.

Dragan Antić, [30], presented a brief overview of sliding mode control techniques implemented in the control of ABS. The most used control algorithms have been applied to a quarter vehicle model to demonstrate the advantages of this control approach, also fast convergence and good performances of the designed controllers verified through digital simulations and validated in real-time applications using a laboratory experimental setup. A series of digital simulations and real-time experiments have been performed for four different control laws, to illustrate the advantages of sliding mode control. The results showed that there is a great agreement between the theoretical and practical results.

E. Zahedi, [31], have presented Fault detection and isolation of Anti-Lock Braking system sensor, he developed the effective sensor faults detection and isolation for ABS. To detect and estimate the possible ABS sensor faults, therefore he used the class of nonlinear system and designed the bank of sliding mode observers (SMOS). He suggested three types of sensor faults in this system bias, drifting, and intermittent fault. The simulation results showed that the proposed algorithm is not only able to detect and isolate the sensor faults, but also it estimates the corresponding sensor faults accurately.

Mehdi Mirzaei, [32], presented an Optimal design of a non-linear controller for an anti-lock braking system. he proposed a nonlinear optimal controller is analytically designed for ABS by the prediction of the wheel slip response from a continuous nonlinear vehicle dynamics model, in this proposed model, he has considered the effects of variations of tire normal load and tire/road condition. An optimal nonlinear wheel slip tracking law has been developed for ABS by the response prediction of a quarter vehicle model. The simulation results showed that the optimality of the control law provides the possibility of regulating the braking pressure easily. Also, the control law is developed in an analytical form that is easy to solve and implement. The method can be easily extended to comprehensive vehicle models.

Rishabh Bhandari, [33], developed three methods to predict different surfaces and accordingly control the wheel slip to achieve maximum friction coefficient for different road surfaces. The surface prediction and control methods are based on a half car model to simulate high-speed braking performance. He compared the performance of the controller which has been developed and four different ABS control algorithms. The results showed that the accuracy of prediction by the proposed methods is very high with error in prediction and the stopping distance is reduced by more than 3% because of prediction for all surfaces.

Vimal Rau Aparow, [34], has presented Modelling and PID control of antilock braking system with wheel slip reduction to improve braking performance. he developed a PID controller for an Antilock Braking System (ABS) using the vehicle longitudinal model, also proposed the vehicle longitudinal model as the ABS plant model to regulate all the four wheels' longitudinal slip at the optimum slip condition ($\lambda = 0.2$) simultaneously. The results showed that the proposed PID controller is

effective in controlling the vehicle longitudinal model and achieves better performance than P, PI, and PD controllers.

Ahmed M. El-Garhy, [35], has presented a Fuzzy Life-Extending Control of Anti-Lock Braking System. He proposed a wear model to provide on-line information about the wear and its variation with system parameters. Nevertheless, the model utilizes the dynamic behavior of the ABS and predicts the wear rates of the brake pads/disc. The system has been modeled and FLEC was designed to control the wear of the brake disc/pads. Based on the predicted wear rates, the proposed fuzzy logic controller modifies its control strategy on-line to keep safe operation leading to an increase in service time of the ABS. The simulation results showed that the wear rate of brake disc/pads is reduced during braking and its temperature is decreased at the end of braking which reduces the brake fading effect, i.e. decreased the friction coefficient between brake disc and pads.

Tohid Sardarmehni, [36], have presented Robust control of wheel slip in the anti-lock brake system of automobiles. He developed a half vehicle model to generate extensive simulation data of the braking system, then compared the performance of two model control systems, one system Fuzzy Logic Control (FLC) and the other Neural Predictive Control (NPC) on tracking the performance of wheel slip in Anti-lock Braking System (ABS). The simulation results showed that a comparative simulation analysis it is shown that the NPC system has a better tracking performance, shorter stopping time, and distance than the FLC controllers. C. Acosta Lúa, [37], have proposed Dynamic Control Applied to a Laboratory Antilock Braking System. A dynamic nonlinear controller has been proposed, based on a state observer of the angular velocities of the two wheels constituting the setup. The acceleration and velocity of the upper wheel, which simulates the automobile wheel, are measurable. The nonlinear dynamic controller designed, ensuring the exponential stability of the system.

CONCLUSIONS

In this paper, some of previous work on the Anti-lock Braking System (ABS) is presented, although several researchers discussed the components of this system and the control techniques used to control this system such as fuzzy logic control, PID control, etc. A few of them discussed faults that may occur in this system that negatively affect the performance of this system, and therefore this system needs a practical study to diagnose faults and improve the performance of this important system that is used in the vehicle.

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