Fuzzy Genetic Algorithm Based Antilock Braking System

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Abstract. In this paper a fuzzy genetic algorithm based anti lock braking system is designed for generating optimum braking torque for vehicles during braking conditions. In this work two fuzzy controllers are used, the first one for road condition estimator and the second is braking torque controller. The fuzzy road condition estimator takes slip ratio and present braking torque as inputs and predicts the road condition. The fuzzy braking torque controller takes present braking torque, current slip, predicted slip and road condition as inputs and generates the braking torque to be applied for next stage. The auto regressive model is used for predicted slip modeling. The braking torque gain of the fuzzy controller and the parameters of the predicted slip model are obtained using genetic algorithm considering optimum stopping distance as the objective function.

Keywords: Anti lock braking system · fuzzy logic controller · genetic algorithm · predicted slip

1 Introduction

Most of the road accidents happen due to ineffective braking. So for the safety of the life of the passengers Anti-locking Braking System (ABS) is necessary. ABS is used in commercial as well as passenger vehicles to perform various functions for the safety of both vehicles and passengers. The ABS helps to improve the steerability, vehicle stability and increases the friction coefficient of vehicle according to road condition. The research publications discuss various methods of performing ABS control system.

Precup et al. [1] proposed a fuzzy control structure using two fuzzy controllers, Takagi-Sugeno and interpolative fuzzy controllers for tire slip control in anti-lock braking systems. Cabrera et al. [2] developed and tested a fuzzy logic based ABS on IMMa test bench system. Oniz et al. [3] used combination of gray system theory and sliding mode control to maintain optimal wheel slip to overcome the nonlinearities and uncertainties. Aksjonov et al. [4] integrated fuzzy theory based electronic stability program with for improving vehicle stability in complex braking situations. Harshal et al. [5] designed linear PID controller to obtain desired braking performance considering

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wheel dimensions. The main disadvantage of using linear controllers here is they are not adaptable to the non-linear changes in road condition with dynamic and non-linear environment changes. Wu et al. [6] designed adaptive fuzzy-neural inference system based ABS for wheel chairs with friction coefficient estimation system. Corno et al. [7] investigated the performance of ABS on snow mobiles and found it has better advantage in improving steering stability rather than stopping distance more especially at cornering. Chen et al. [8] analyzed the performance of ABS using electro hydraulic brakes with proportional pressure valve and found it is more useful for obtaining better slip control with more safety. Fedin et al. [9] proposed artificial neural network based ABS for road surface prediction and braking torque control. He et al. [10] embedded time-varying asymmetric barrier Lyapunov Function into non liner controllers design for handling slip ratio constraints and to avoid self locking of brakes. Xue et al. [11] discussed the performance and the practical possibilities of ABS methodologies available in the literature. Wei et al. [12] proposed road friction coefficient estimation based method for designing an effective and adaptable ABS. Fernandez et al. [13] developed fuzzy and evolutionary techniques based ABS to adapt the changes in road adherence conditions. Lupberger et al. [14] work proposed a robust nonlinear controller design for tracking of wheel speed. After surveying all recent control technologies, in this paper an effective fuzzy logic based ABS is developed by considering a quarter car model. In this work two fuzzy controllers are designed the first one to estimate the road condition and the second one to control the braking torque using predicted slip. The slip prediction model coefficients and braking torque controller gains are obtained using Genetic Algorithm (GA) considering stopping distance as the objective function.

2 Dynamics of Vehicle Wheel

It is usual practice to model a physical system into mathematical form before implementing any controller practically. The mathematical form of a vehicle which is selected to operate by using ABS is modelled by single wheel vehicle model is shown in Fig. 1.

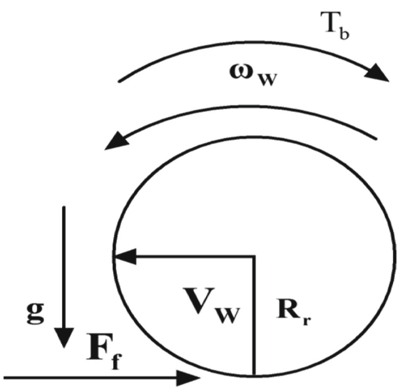

Fig. 1. Quarter car model

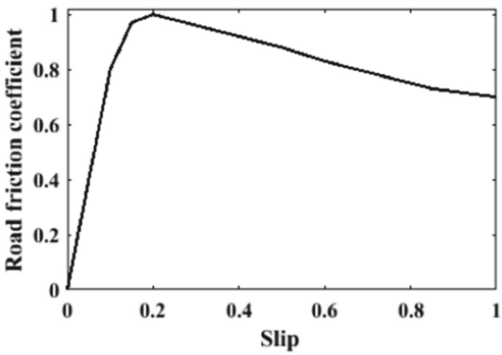

Fig. 2. Slip friction curve

For simplicity quarter car model is considered and the equations to represent the dynamics of the vehicle wheel are given by the following equations.

$$m\frac{dV_V}{dt} = -F_f \tag{1}$$

$$J\frac{d\omega_W}{dt} = F_f R_r - T_b \tag{2}$$

$$F_f = \mu\, m\, g \tag{3}$$

$$V_W = \omega R_r \tag{4}$$

where ‘m’ is the mass and V_v is the vehicle velocity from Newton’s second law of motion. J is the moment of inertia, ω_W is the wheel angular velocity, R_r is the Radius of wheel and T_b is the braking torque applied on the vehicle. μ is the road friction coefficient and ‘g’ is the acceleration of gravity.

There exists difference between wheel velocity and vehicle velocity. Slip (λ) is the difference between vehicle velocity (V_V) and wheel velocity (V_ω).

$$\lambda = \frac{V_V - V_\omega}{V_V} \tag{5}$$

So slip is a very important parameter, it varies from 0 to 1.

The road friction coefficient can be estimated from the slip friction curve and it is shown in Fig. 2.

3 Fuzzy GA Methodology

In the present work Fuzzy Genetic algorithm methodology is developed for estimating the optimum braking torque. The braking torque controller is developed using two stage fuzzy controllers. Initially in the first stage the road condition is estimated using present

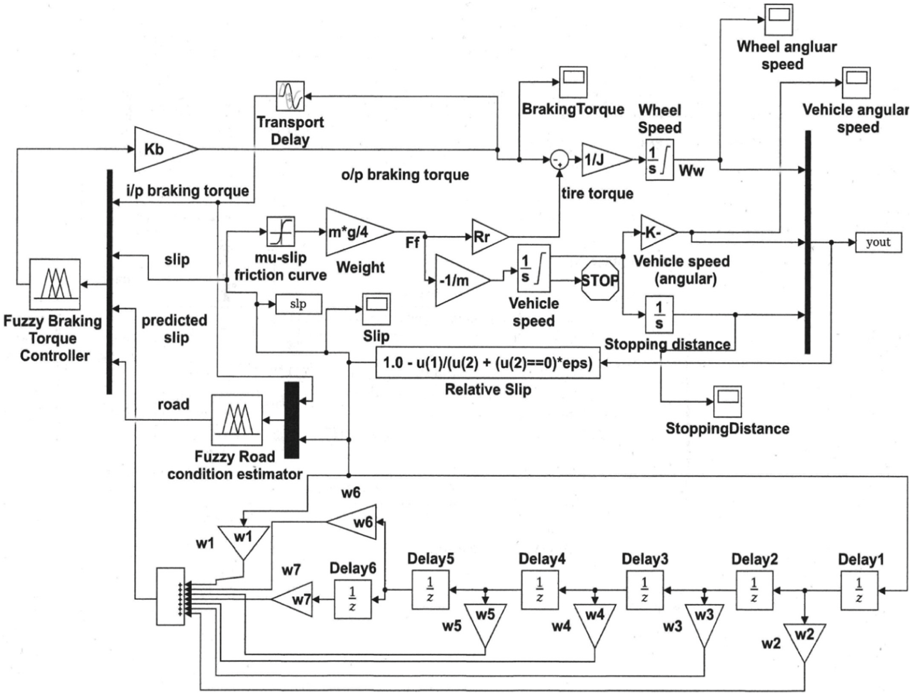

Fig. 3. MATLAB Simulink diagram of Fuzzy GA ABS

braking torque and slip ratio. In the second stage fuzzy controller takes the input of braking torque, slip ratio, predicted slip ratio and road condition as inputs and estimates the output braking torque. The MATLAB simulink diagram developed antilock braking controller is shown in the following Fig. 3. The parameters of braking torque controller gain (K_b) and predictive slip model are obtained using GA considering minimizing the stopping distance as objective function.

3.1 Fuzzy Road Condition Estimator

The fuzzy road condition estimator takes present braking torque and slip ratio as inputs and gives estimated road condition as outout. The member ship functions for braking torque, slip ratio and road friction coefficient are given in the Following Fig. 4, Fig. 5 and Fig. 6.

The rule base developed for the fuzzy road condition estimator is given by the following fuzzy rules.

1. If (IBT is **me**) and (SR is **me**) Then (road is **wet**).
2. If (IBT is **la**) and (SR is **zs**) Then (road is **dry**).
3. If (IBT is **zs**) and (SR is **la**) Then (road is **ice**).

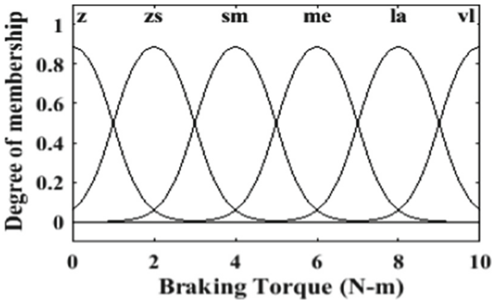

Fig. 4. Input braking Torque (IBT).

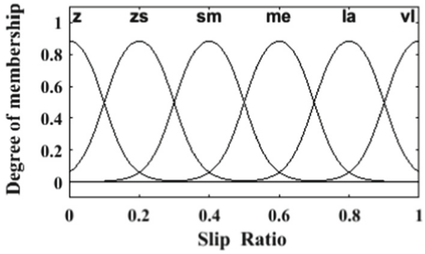

Fig. 5. Slip ratio (SR).

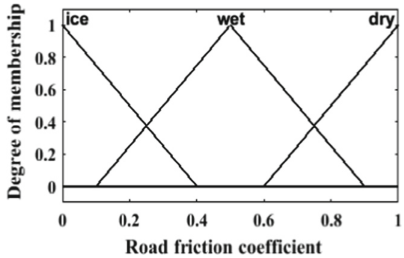

Fig. 6. Road friction coefficient (road).

3.2 Fuzzy Braking Torque Controller

The fuzzy braking torque controller takes braking torque, present slip, predicted slip and road condition as input and gives output as braking torque to be applied for stopping the vehicle at optimum distance.

The predicted is modeled considering auto regressive modeling and the gains are estimated using GA considering the minimum stopping distance as the objective function. The auto regressive predictive slip modeling is given by the following Eq. (6).

$$PSR(t+1) = w_1 PSR(t) + \sum_{i=2}^{7} w_i PSR(t-i+1) \tag{6}$$

The membership functions for output braking torque and predictive slip are shown in Figs. 7 and 8.

The rule base required for generating the output braking torque is given by the following fuzzy rules.

1. If (PSR is **not vl)** and (road is **dry)** Then (OBT is **la**).
2. If (IBT is **la**) and (SR is **la**) and (PSR is **not vl**) and (road is **dry)** Then (OBT is **me)**.
3. If (IBT is **la)** and (SR is **sm**) and (PSR is **not vl**) and (road is **dry**) Then (OBT is **me**).
4. If (IBT is **la)** and (SR is **me)** and (PSR **not vl**) and (road is **dry**) Then (OBT is **la**).
5. If (IBT is **zs)** and (SR is **zs**) and (road is **ice**) Then (OBT is **zs**).
6. If (SR is **z)** and (road is **ice**) Then (OBT is **sm**).
7. If (SR is **sm**) and (road is **ice**) Then (OBT is **z**).
8. If (SR is **vl)** and (PSR **not vl)** Then (OBT is **z**).
9. If (SR is **zs)** and (PSR **not vl)** and (road is **wet**) Then (OBT is **sm**).
10. If (SR is **sm)** and (road is **wet**) Then (OBT is **zs**).
11. If (SR is **z)** and (PSR **not vl)** and (road is **wet**) Then (OBT is **sm**).

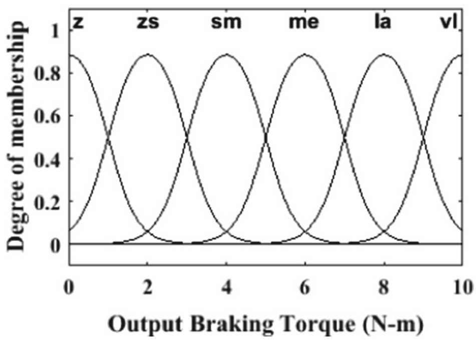

Fig. 7. Output braking Torque.

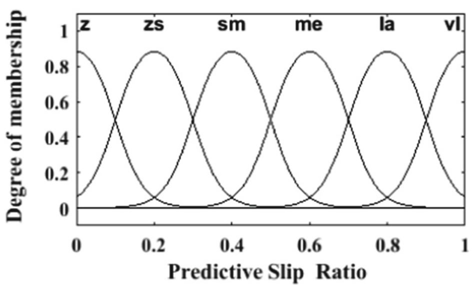

Fig. 8. Predictive Slip ratio (PSR).

4 Results and Discussions

The fuzzy GA based antilock braking system is designed considering the quarter vehicle model. The parameters of the quarter vehicle model are shown in the following Table 1 [15].

The parameters of the predictive slip model obtained using genetic algorithm is shown in Table 2.

The braking torque gain obtained using GA is $K_b = 15.0$. The slip road friction curve is shown in Fig. 2.

The optimum stopping distance comparison with proposed Fuzzy GA controller approach and bang bang controller is shown in Fig. 9. The optimum stopping distance with Bang bang controller is 219.68 m and obtained with proposed fuzzy GA controller is 160.72 m which is much better compared with Bang bang controller.

The vehicle angular velocity and wheel angular velocity as the vehicle gradually comes to stopping position is shown in Fig. 10 with the proposed approach.

The convergence of the stopping distance with number of generations with the fuzzy GA approach is shown in Fig. 11. It is observed that during the braking mode operation the slip is maintained around 0.2 which is most comfortable for vehicle safety.

Table 1. Vehicle parameters

Wheel radius (R_r)	0.381 m
Moment of Inertia (I)	6.77 kg m^2
Mass of the Vehicle (m)	22.68 kg
Acceleration of gravity (g)	9.81 m/s^2
Initial Velocity (V_0)	26.82 m/s

Table 2. Predictive Slip Model Parameters

w_1	0.18745098
w_2	0.13921569
w_3	0.15215686
w_4	0.16705882
w_5	0.12392157
w_6	0.13686275
w_7	0.19137255

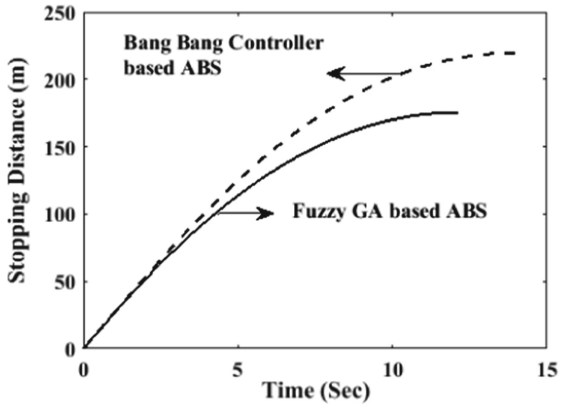

Fig. 9. Stopping distance

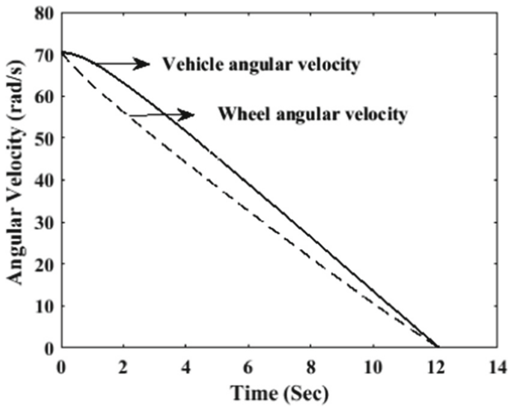

Fig. 10. Angular velocity

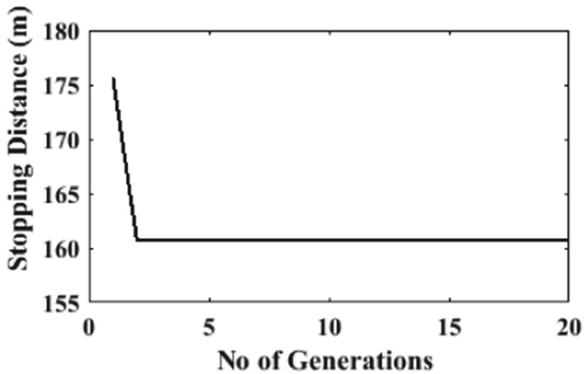

Fig. 11. Fuzzy GA convergence graph

5 Conclusions

In the present work a fuzzy genetic algorithm based antilock braking system is developed for applying optimum braking torque. The parameters of the predicted slip model, fuzzy braking torque gains are optimized using genetic algorithm considering the stopping distance as the objective function. MATLAB simulink models are developed for antilock braking system for performing the simulations. The performance of the proposed antilock braking system is compared with conventional bang bang controller. From the simulation results it is observed that the proposed fuzzy based antilock braking system is much better is minimizing the stopping distance while maintaining better ride quality for the passengers.

References

1. Precup, R.E., Preitl, S., Balas, M., Balas, V.: Fuzzy controllers for tire slip control in anti-lock braking systems. In: 2004 IEEE International Conference on Fuzzy Systems, vol. 3, pp. 1317–1322 (2004)
2. Cabrera, J.A., Ortiz, A., Castillo, J.J., Simon, A.: A fuzzy logic control for antilock braking system integrated in the IMMa tire test bench. IEEE Trans. Veh. Technol. **54**(6), 1937–1949 (2005)
3. Oniz, Y., Kayacan, E., Kaynak, O.: A dynamic method to forecast the wheel slip for antilock braking system and its experimental evaluation. IEEE Trans. Syst. Man Cybern. Part B (Cybern.) **39**(2), 551–560 (2008)
4. Aksjonov, A., Augsburg, K., Vodovozov, V.: Design and simulation of the robust ABS and ESP fuzzy logic controller on the complex braking maneuvers. Appl. Sci. **6**(12), 382 (2016)
5. Harshal, M.R., Digrase, A.A., Wayse, A.V.: Linear PID control technique for single wheel ABS (anti-lock braking system) of motorcycle. In: 2017 2nd International Conference for Convergence in Technology (I2CT). IEEE (2017)
6. Wu, B.F., Chang, P.J., Chen, Y.S., Huang, C.W.: An intelligent wheelchair anti-lock braking system design with friction coefficient estimation. IEEE Access **6**, 73686–73701 (2018)
7. Corno, M., et al.: Experimental validation of an antilock braking system for snowmobiles with lateral stability considerations. IEEE Trans. Control Syst. Technol. **28**(2), 705–712 (2018)
8. Chen, C., Mao-Hsiung, C.: Mathematical simulations and analyses of proportional electro-hydraulic brakes and anti-lock braking systems in motorcycles. Actuators **7**(3) (2018)
9. Fedin, A., Yaroslav, K., Evgeniy, M.: ANN in car antilock braking systems modeling. In: Dynamics of Complex Networks and their Application in Intellectual Robotics (2019)
10. He, Y., Lu, C., Shen, J., Yuan, C.: Design and analysis of output feedback constraint control for antilock braking system with time-varying slip ratio. In: Mathematical Problems in Engineering (2019)
11. Xue, X., Cheng, K.W.E.: Electric antilock braking systems for electric vehicles. In: 2020 8th International Conference on Power Electronics Systems and Applications (PESA). IEEE (2020)
12. Wei, J.: Vehicle velocity and road friction coefficient estimation for anti-lock braking system. In: 2020 International Automatic Control Conference (CACS). IEEE (2020)
13. Fernández, J.P., Vargas, M.A., García, J.M.V., Carrillo, J.A.C., Aguilar, J.J.C.: Coevolutionary optimization of a fuzzy logic controller for antilock braking systems under changing road conditions. IEEE Trans. Veh. Technol. **70**(2), 1255–1268 (2021)

14. Lupberger, S., Degel, W., Odenthal, D., Bajcinca, N.: Nonlinear control design for regenerative and hybrid antilock braking in electric vehicles. IEEE Trans. Control Syst. Technol. (2021)
15. Srikanthan, P., Udaya Moorthi, K.T., Vigneshwaran, S.K., Ram, S.J., Narai, R.A.: Vehicle slip controller by means of antilock braking system with CAN bus and a simulation in MATLAB. Int. J. Latest Res. Sci. Technol. **2**(1), 525–529 (2013)