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Anti-Lock Braking System Control using Backstepping Method Based Fuzzy Logic

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Abstract: The Anti-Lock Braking system (ABS) is one of most important safety systems of vehicles which must be controlled effectively. In this paper, we are concerned on controlling an Anti-Lock Braking system of an autonomous vehicle using a nonlinear Backstepping control method based on Takagi Sugeno (T-S) Fuzzy Logic method, employing Lyapunov approach to study the system stability. In the first step, we apply the Backstepping control method to the system in order to control it by studying its stability using Lyapunov approach. The second step consists on adding the Fuzzy Logic technique for the aim to optimize the objective function that can provide a desired level of stability to the Anti-Lock Braking system. The simulation of results found shows the accuracy of our proposed control strategy.

Keywords: Anti-lock braking system, Backstepping control, Nonlinear system, T-S fuzzy logic.

1. Introduction

An Anti-Lock Braking System (ABS) is one of important safety systems of vehicles. It prevents the wheels from self-locking during braking, which offers the possibility of maintaining steering control of the vehicle. Driving without the Anti-Lock Bracking System (ABS) is entirely possible, but increases the risk of accidents. Therefore, it is necessary to improve the vehicles safety by using the ABS [1, 2]. For that, the control of this system is very important and must be accurate and efficient for the aim to control the wheel slip at its optimum value [3, 4]. Therefore, the backstepping control method is proposed to control the ABS which is a developed control method that consists in forcing the system to pursue the desired value in a finite time and with certain conditions to respect in order to ensure the system stability, and provides effective results [5-7]. In order to improve the system control, to keep the system in a desired level of stability and to reach better results, the T-S Fuzzy Logic method is proposed to optimize the objective function that is designed to keep the system stable [8-10]. Generalizing the control law requires the study of system stability using Lyapunov approach [11, 12].

The main objective in our works concerns controlling the ABS system using Backstepping Control method, optimizing the objective function of stability using the T-S fuzzy Logic technique and studying the system stability using Lyapunov approach in order to generalize the control law respecting the stability conditions [13-16].

The efficiency of our control strategy proposed is evaluated and shown in the simulations of results achieved.

This paper is organized as follows: Section 2 concerns the ABS system modelling. In Section 3, we present the control strategy proposed. Then in Section 4, the T-S Fuzzy Logic method is presented. After that, we present in Section 5 the simulations of results found. Finally, a conclusion is presented in Section 6.

2. ABS System Modeling

It is necessary to study the mathematical model of the ABS system in order to control it [2]. Fig. 1 represents the wheel model.

The ABS system contains some important units as an electronic control unit, a hydraulic control unit and sensors of speed in each wheel as shown in Fig. 2.

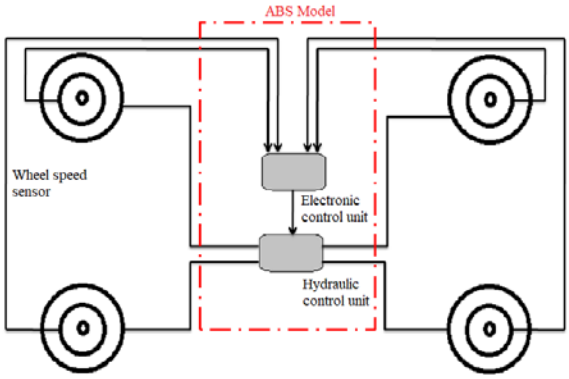


Fig. 1. Wheel model.

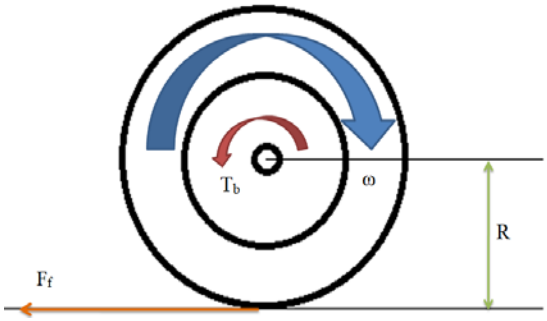


Fig. 2. Anti-Lock Braking model.

Using Newton-Euler formalism, we represent the ABS model by a system of differential equations expressing the velocity v, the angular velocity ω and the slip coefficient λ [1].

$$\begin{cases} \dot{v} = -g.\mu \\ \dot{\omega} = \frac{1}{J}(m.g.\mu.R - T_b) \end{cases} \quad (1)$$

$$\dot{\lambda}(t) = f(\lambda, t) + h(\lambda, t).u(\lambda, t)\,, \quad (2)$$

where f and h are the system dynamics, with:

$$\begin{cases} f(\lambda, t) = \left[\frac{\dot{v}}{v}(1-\lambda) - \frac{m.g.R^2}{v}\mu\right] \\ h(\lambda, t) = \frac{R}{v} \end{cases} \quad (3)$$

$u = T_b$ is the control law that will be studied in the next section which represents the braking torque and $\mu = F(\lambda)$ is the friction coefficient.

With

$$F(\lambda) = c_1\left(1 - e^{-c_2\lambda}\right) - c_3\lambda\,, \quad (4)$$

where c_1, c_2 and c_3 are constant coefficients.

3. Control Strategy

In this work, we are interested in controlling the ABS system using Backstepping control method based on the T-S Fuzzy Logic methodology [5, 7, 17].

To apply this method in the ABS system, we firstly define the tracking error in the following form:

$$\begin{cases} e = \lambda_d - \lambda \\ \dot{e} = \dot{\lambda}_d - \dot{\lambda} \end{cases} \quad (5)$$

Then, we define the Lyapunov function to study the system stability in order to generalize the control law [11][18].

$$V_1 = \frac{1}{2}e^2 > 0 \quad (6)$$

The derivative of the Lyapunov function must be negative to ensure the system stability.

$$\begin{aligned} \dot{V}_1 &= e.\dot{e} < 0 \\ &= e.\left(\dot{\lambda}_d - f(\lambda, t) - h(\lambda, t).u(\lambda, t)\right) \end{aligned}$$

We assume that:

$$\dot{V}_1 = -\alpha.e^2 \leq 0, \quad (7)$$

where $\alpha > 0$ is a constant coefficient.

Then, we define the control law of the system:

$$u(\lambda, t) = \frac{1}{h(\lambda, t)}\left(\dot{\lambda}_d - f(\lambda, t) + \hat{\alpha}(\lambda, \theta_\alpha).e\right), \quad (8)$$

where $\hat{\alpha}(\lambda, \theta_\alpha)$ is the optimal objective function that will be studied using the T-S Fuzzy Logic technique in the next section.

4. T-S fuzzy Logic

In this section, we present the T-S Fuzzy Logic method used in the ABS system to optimize the objective function that keeps the system in a desired level of stability, in order to achieve better results respecting the conditions of system stability using Lyapunov approach [19-21].

We define first the membership functions chosen as follows:

$$\mu_i = e^{-(-\left(\frac{\lambda_j - c_i}{(2\sigma_i)^2}\right))}; \; i = 1,2 \tag{9}$$

Then, the inference phase consists on a collection of IF-THEN rules which are defined in the following form [22-24], if x_1 is α_1^j and....., ... and x_n is α_n^j then α_j is θ_j

Finally, it is necessary to deduce the output of the fuzzy system using Lyapunov approach to ensure the system stability, which is expressed as follows:

$$\hat{\alpha}(\lambda, \theta_\alpha) = \frac{\sum_{j=1}^{k} \theta_j (\prod_{i=1}^{n} \mu_{\alpha_i^j}(\lambda_i))}{\sum_{j=1}^{k} (\prod_{i=1}^{n} \mu_{\alpha_i^j}(\lambda_i))} = {\theta_\alpha}^T . \xi(\lambda) \tag{10}$$

We assume the expression of the Lyapunov function:

$$V_2 = \frac{1}{2} e^2 + \frac{1}{2\gamma} . \Phi_\alpha . {\Phi_\alpha}^T > 0 \tag{11}$$

with:

$$\Phi_\alpha = \theta_\alpha - {\theta_\alpha}^* , \tag{12}$$

where θ_α is the optimal parameter, and:

$${\theta_\alpha}^* = \arg\min(\sup_{\lambda \epsilon R} |\alpha(\lambda, t) - \hat{\alpha}(\lambda, \theta_\alpha)|) \tag{13}$$

The derivative of the Lyapunov function must be negative [12][18].

$$\begin{aligned} \dot{V}_2 &= e . \dot{e} + \frac{1}{\gamma} . \Phi_\alpha . \dot{\Phi}_\alpha \leq 0 \\ &= e . \left(\dot{\lambda}_d - f(\lambda, t) - h(\lambda, t) . u(\lambda, t)\right) \\ &\quad + \frac{1}{\gamma} . \Phi_\alpha . \dot{\Phi}_\alpha \\ &= e . \left((\hat{\alpha}(\lambda, {\theta_\alpha}^*) - \hat{\alpha}(\lambda, \theta_\alpha)) . e\right. \\ &\quad \left. - \hat{\alpha}(\lambda, {\theta_\alpha}^*) . e\right) \\ &\quad + \frac{1}{\gamma} . \Phi_\alpha . \dot{\Phi}_\alpha \end{aligned} \tag{14}$$

From (10) we find:

$$\begin{aligned} \dot{V}_2 &= e . (-\Phi_\alpha . \xi(\lambda) . e - \hat{\alpha}(\lambda, {\theta_\alpha}^*) . e) + \frac{1}{\gamma} . \Phi_\alpha . \dot{\Phi}_\alpha \\ &= \frac{1}{\gamma} . \Phi_\alpha . \left(\dot{\Phi}_\alpha + e^2 . \gamma . \xi(\lambda)\right) - \hat{\alpha}(\lambda, {\theta_\alpha}^*) . e^2 \end{aligned}$$

Taking $\dot{\Phi}_f + e^2 . \gamma . \xi(\lambda) = 0$, we extract the expression of θ_α.

After calculations we obtain:

$$\dot{V}_2 = -\hat{\alpha}(\lambda, {\theta_\alpha}^*) . e^2 \tag{15}$$

Then $\hat{\alpha}(\lambda, {\theta_\alpha}^*)$ must verify the following condition to ensure the system stability.

$$\hat{\alpha}(\lambda, {\theta_\alpha}^*) \geq 0 \tag{16}$$

and

$$\theta_\alpha = \gamma . e^2 . \xi(\lambda) \tag{17}$$

5. Simulation of Results

In order to evaluate the performance of our control strategy proposed, we did many simulations of results found.

First, we employed the Backstepping control method in the ABS system to control the wheel slip and regulate it to its optimum value, which is chosen as follows: $\lambda_d = 0.15$. Then, we add the T-S Fuzzy Logic method to optimize the objective function that provides a desired level of stability to the system.

We simulate the braking torque T_b generated by the Backstepping control method using Fuzzy Logic method.

Fig. 3 shows the evolution of the control law obtained using our control strategy proposed.

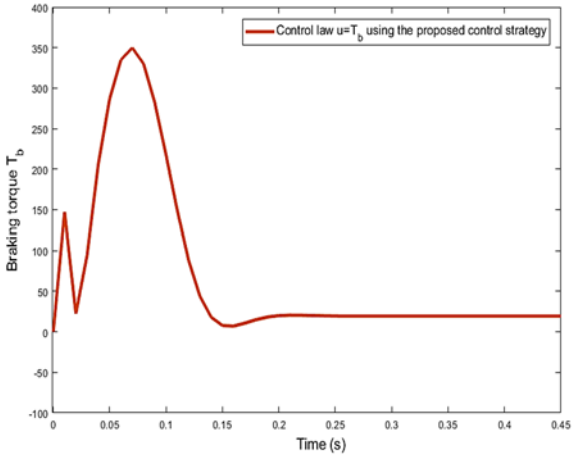


Fig. 3. The control law obtained by the proposed control method using Fuzzy Logic.

We employed the Fuzzy Logic method in the system control for the aim to achieve better results by getting a fast response of convergence.

Fig. 4 represents the evolution of the wheel slip using the control strategy proposed with and without Fuzzy Logic method, which it can be seen that using the Fuzzy Logic in the system control is efficient; the convergence is faster than without using it.

We simulate the tracking error between the desired value to reach and the wheel slip reached using our control strategy with and without the Fuzzy Logic.

Fig. 5 shows that the tracking error converges to 0 in a finite time using the control strategy proposed, but faster when using the Fuzzy Logic method.

After that, we simulate the speed obtained using the proposed backstepping control method with and without Fuzzy logic to demonstrate the accuracy of our proposed control strategy.

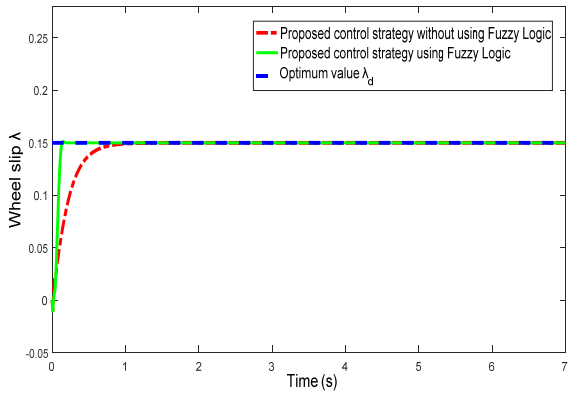


Fig. 4. The evolution of the wheel slip obtained by the proposed control strategy with and without Fuzzy Logic.

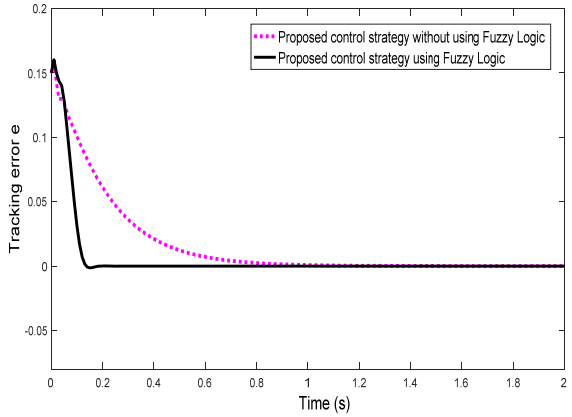


Fig. 5. The evolution of the tracking error between the wheel slip and the desired value.

Fig. 6 shows the evolution of the speed achieved using our control strategy proposed where the effectiveness of the Fuzzy Logic method in the system control is clearly shown, which the speed converges to 0 in faster time when using our control strategy proposed.

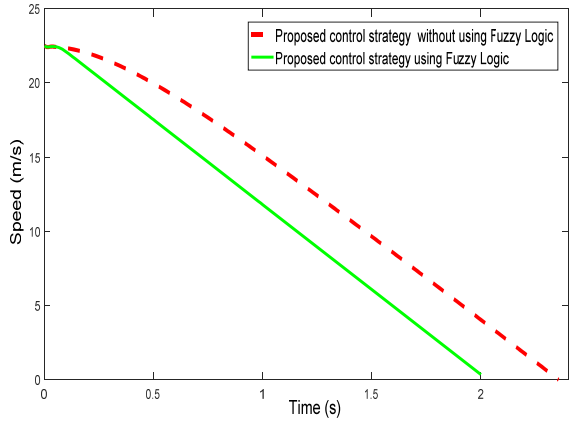


Fig. 6. The evolution of the speed obtained using the control strategy proposed.

The results show the efficiency of our proposed control strategy using the Backstepping control method combined with the T-S Fuzzy Logic method.

6. Conclusion

In this work, we presented the Backstepping control method for controlling an Anti-Lock Braking System, combined with T-S Fuzzy Logic method to optimize the system dynamics in order to reach better results. The generalization of the control law requires the study of system stability using Lyapunov approach.

The efficiency of our proposed control strategy is shown in the results simulation, and adding Fuzzy Logic method makes the system control more accurate.

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