INTELLIGENT BRAKING SYSTEM USING FUZZY LOGIC AND SLIDING MODE CONTROLLER

Peyman Naderi,* Amir R. Naderipour,** Mojtaba Mirsalim,*** and Mohammad A. Fard****

Abstract

In this paper, an antilock–antiskid braking system controller, which has been designed for stability enhancement of vehicles during braking and turning, is presented. Using available signals, a novel structure is proposed for vehicle stability improvement for critical driving conditions such as braking on slippery or μ-split road surfaces. In conventional vehicles, undesired lane changes may occur due to equal dispatch of braking torques to all wheels simultaneously. Also, intensive pressure on brake pedal can bring about wheel lockup which results in vehicle instability and undesired lane changes. Antilock braking system (ABS) along with Antiskid braking system (ASBS) can serve as a driver-assistance system in vehicle path correction facing critical driving conditions during braking and turning round on different road surfaces. For these purposes, at first, a trained Neuro-Fuzzy estimator is used for vehicle path prediction according to vehicle’s speed, applied steering angle and their changes. Then, slip of each wheel will be controlled by an antilock fuzzy controller which has been designed for each wheel. Also, a sliding mode controller has been designed so as to control the yaw angle considering the yaw error, where the yaw error is resulted from the difference of the Neuro-Fuzzy estimator’s output and actual yaw angle. Then, the difference of the left and the right wheels’ braking torques are used by the sliding mode controller in order to reduce the yaw error. Considering a model of three-degree-of-freedom for chassis and one-degree-of-freedom Dugoff’s tire model for each wheel, a series of Matlab/Simulink simulation results will be presented to validate the effectiveness of the proposed controller. Finally, a comparison will be made between the proposed method and one of the recent control systems which shows the superiority of its performance.

Key Words

Fuzzy, slip of wheel, hybrid, sliding mode, SUGINO form

Nomenclature

\( a_x \) Longitudinal acceleration of vehicle
\( a_y \) Lateral acceleration of vehicle
\( C_x \) Longitudinal stiffness of tire
\( C_y \) Lateral stiffness of tire
\( CG \) Corresponding to vehicle centre of gravity
\( Fl \) Corresponding to front left
\( Fr \) Corresponding to front right
\( Rl \) Corresponding to rear left
\( Rr \) Corresponding to rear right
\( F_{zi} \) Longitudinal force of ith wheel
\( F_{yi} \) Longitudinal force of ith wheel
\( F_{Ri} \) Rolling resistance of ith wheel
\( F_{ax} \) Longitudinal aerodynamic drag force
\( F_{ay} \) Lateral aerodynamic drag force
\( h_{cg} \) Height of CG
\( I_w \) Wheel’s moment of inertia
\( I_z \) Vehicle moment of inertia around z axis
\( L_f \) Distance of CG from front axle
\( L_r \) Distance of CG from rear axle
\( M_t \) Total mass of vehicle
\( M_z \) Self-aligning torque of tire
\( R_w \) Wheel’s radius
\( r \) Yaw rate of vehicle
\( T_a \) Length of vehicle axles
\( T \) Applied torque to wheel
\( u \) Longitudinal velocity of CG
\( v \) Lateral velocity of CG
\( X, Y \) Denotation of static reference frame
\( x, y \) Denotation of moving reference frame
\( \alpha \) Slip angle of wheel
\( \psi \) Yaw angle of vehicle
\( \delta \) Steering angle
\( \lambda \) Longitudinal slip of wheel

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μ<sub>peak - i</sub> Friction coefficient for ith wheel

ω Angular speed of wheel

τ<sub>Ri</sub> Rolling resistance torque of ith wheel

τ<sub>Left</sub> Applied torque to left wheels

τ<sub>Right</sub> Applied torque to right wheels

1. Introduction

Antilock-antiskid braking system (ALASB), comprising electrical sensors and intelligent controllers, is a new method as a driver-assistance system for safe and secure braking. In ALASB, braking force is initiated by the driver which is applied separately to wheels, according to vehicle undesired yaw angle, in order to enhance vehicle stability. Such aims have recently attracted much interest from both industry and academic sectors, globally. Hence, a great deal of new research works has been performed for better control and higher safety in vehicles. The three most common methods of lateral and yaw stability realizations are as follows:

1. Active steering control (ASC)
2. Differential wheel braking (DWB)
3. Differential traction control (DTC)

The steering control is relatively an old method which has been proposed in [1,2]. In [1], a control-oriented model has been proposed that decouples the tire forces, and facilitates control algorithm development. A yaw control system via steering, utilizing a fuzzy controller, has been introduced in [2] for a 4WD vehicle. The idea of differential braking was first proposed as a steering intervention in [3], and has been used in [4] for yaw stability control. The Brake-by-wire (BBW) system, for undesired lane change and yaw angle control, has been proposed in [5]. In the latter, a fuzzy controller has been used to obtain the difference of the left and the right wheels’ braking torques in the case of lateral deviation, large yaw angle or yaw’s instability to get the vehicle back on track, and restores its stability. While, wheel saturation due to extra applied braking torque – antilock braking – was not considered in this paper.

In [6], sliding mode controller has been exploited for yaw rate control via electrical traction system which is installed on the rear wheels of the electrical vehicle; also, has been used in [7] for a 4WD hybrid vehicle. While, in [8], instead of sliding mode controller, a fuzzy controller has been utilized for this purpose in a 4WD hybrid vehicle. Likewise, in all [6–8], the wheel’s slip has not been controlled nor has been investigated the differential braking. Differential braking outperforms steering method, and can be easily realized through providing optimal braking torques on different wheels for antiskid and antilock operation.

This paper is organized as follows: In Section 2, the proposed system’s architecture will be presented. In Section 3, a discussion will be made on the whole vehicle model. In Section 4, a trained Neuro-Fuzzy estimator will be illustrated for vehicle lane estimation. In Section 5, ALASB control strategy will be dealt. In Section 6, simulation results and a comparison will be presented which shows the outstanding performance of the proposed method.

2. ALASB System Architecture and Aims

The ALASB architecture is illustrated in Fig. 1 which consists of four antiskid fuzzy controllers in SUGINO form. Each module is relevant to each wheel, and the braking force applied to each one is computed based on the input braking force, wheel slip and its changes. When the driver breaks on slippery road, during turning or on μ-split road surface, the vehicle is needed to behave the same as it does on a normal road surface; thus, in this method, braking force will be reduced by this controller to avoid wheel lockup. Moreover, braking forces from the left and the right controllers will be computed by another sliding mode controller (ASBS) in order to avoid vehicle skidding and undesired lane change during braking. For this purpose, a Neuro-Fuzzy estimator can be devised and trained to obtain a reference yaw angle to be applied as an input to the sliding mode controller.

3. Vehicle and Tire Modelling

A model of seven degree-of-freedoms was used for simulation, where three degrees are pertinent to the chassis dynamics, and four degrees are relevant to wheels angular speed. Also, fl, fr, rl, and rr are representing front left, front right, rear left and rear right, respectively.
3.1 Vehicle and Body Modelling

In this model, regarding the delineated parameters in the nomenclature, the system’s dynamics can be described as follows [5,6]:

\[
M_i(\dot{\nu} - rv) = F_{xfi} \cos \delta - F_{yfi} \sin \delta + F_{xfi} \cos \delta \\
+ F_{yfi} \sin \delta + F_{xrl} + F_{xrr} - F_{ax}
\] (1)

\[
M_i(\dot{\nu} + ru) = F_{xfi} \sin \delta + F_{yfi} \cos \delta + F_{xfi} \sin \delta \\
+ F_{yfi} \cos \delta + F_{yrl} + F_{yrr} - F_{ay}
\] (2)

\[
I_i \dot{\omega}_i = L_f [F_{xfi} \sin \delta + F_{yfi} \cos \delta + F_{xfi} \sin \delta + F_{yfi} \cos \delta] \\
- L_r [F_{yrl} + F_{yrr}] + \frac{T_a}{2} [F_{xfi} \cos \delta - F_{yfi} \sin \delta] \\
- F_{xfi} \cos \delta + F_{yfi} \cos \delta + F_{xrl} - F_{xrr}
\] (3)

3.2 Tire Model

Tire modelling is one of the most important and rather sophisticated parts of a vehicle modelling. Applying revolving torque \(\tau_w\) on the wheel, the rotation can be expressed as:

\[
I_w \omega_i = T_i - R_w F_{xi} - \tau_{ri} \quad \text{for i: fl, fr, rl, rr}
\] (4)

\[
\tau_R = C_0 F_z + C_1 |V_w|^2
\] (5)

where, \(I_w\) and \(R_w\) are wheel’s moment of inertia and wheel’s radius, respectively, \(\omega\) is wheel’s angular velocity. \(\tau_R\) is wheel’s rolling resistance torque which is an important factor in fuel consumption computing. \(V_w\) is wheel’s linear velocity; \(C_0\) and \(C_1\) are constants which are usually: 0.04 ≤ \(C_0\) ≤ 0.2, \(C_1 \ll C_0\).

The well-known Dugoff’s model has been utilized for longitudinal and lateral forces modelling in this article [5–8]. \(F_z\) is the vertical force on the tire, and, considering the effects of vehicle’s longitudinal and lateral accelerations, can be obtained via the definite formulae given in [6].

\[
\mu_i = \mu_{peak,i} \sqrt{1 - A_2 \cdot \frac{R_w \lambda_i + \tan(\alpha_i)}{a_x}}
\] (6)

\[
H_i = \left[ \left( \frac{C_x \lambda_i}{\mu_i F_{zi}(1 - \lambda_i)} \right)^2 + \left( \frac{C_y \tan(\alpha_i)}{\mu_i F_{zi}(1 - \lambda_i)} \right)^2 \right]^{1/2}
\] (7)

\[
F_{xi} = \begin{cases} 
\frac{C_x \lambda_i}{1 - \lambda_i} & \text{for } H_i < 0.5 \\
\frac{C_x \lambda_i}{1 - \lambda_i} \left( \frac{1}{H_i} - \frac{1}{4H_i^2} \right) & \text{for } H_i \geq 0.5
\end{cases}
\] (8)

\[
F_{yi} = \begin{cases} 
\frac{C_y \tan(\alpha_i)}{1 - \lambda_i} & \text{for } H_i < 0.5 \\
\frac{C_y \tan(\alpha_i)}{1 - \lambda_i} \left( \frac{1}{H_i} - \frac{1}{4H_i^2} \right) & \text{for } H_i \geq 0.5
\end{cases}
\] (9)

Figure 2 shows sample curves for various values of \(\lambda\) and \(\alpha\) which can be obtained from (6) to (9). According to these curves, when the longitudinal slip \(\lambda\) and slip angle \(\alpha\) are small, the coupling between \(F_x\) and \(F_y\) is so little, so can be ignored. Whereas, when the longitudinal slip is large, \(F_y\) decreases for all values of \(\alpha\) which indicates unsteerability condition. This case might occur due to high \(\lambda\) which could happen during takeoff and hard braking situations.

Equations expressing the vertical forces on the tires are given as below:

\[
F_{zi} = \frac{M_t}{(L_f + L_r)} \left[ g \cdot \frac{L_r}{2} + \frac{a_x \cdot h_{cg}}{2} + \frac{a_y \cdot L_r \cdot h_{cg}}{T_a} \right]
\] (10)

\[
F_{zi} = \frac{M_t}{(L_f + L_r)} \left[ g \cdot \frac{L_r}{2} - \frac{a_x \cdot h_{cg}}{2} - \frac{a_y \cdot L_r \cdot h_{cg}}{T_a} \right]
\] (11)

\[
F_{xrl} = \frac{M_t}{(L_f + L_r)} \left[ g \cdot \frac{L_f}{2} + \frac{a_x \cdot h_{cg}}{2} + \frac{a_y \cdot L_f \cdot h_{cg}}{T_a} \right]
\] (12)

\[
F_{xrr} = \frac{M_t}{(L_f + L_r)} \left[ g \cdot \frac{L_f}{2} - \frac{a_x \cdot h_{cg}}{2} - \frac{a_y \cdot L_f \cdot h_{cg}}{T_a} \right]
\] (13)

where, \(a_x = \dot{\nu} - rv\) and \(a_y = \dot{\nu} + ru\) denote the longitudinal and lateral accelerations of CG, respectively. The longitudinal slip of a wheel can be obtained from:

\[
\lambda_i = \frac{R_w \cdot \omega_i - |V_w| \cdot \cos(\alpha_i)}{\max(R_w \cdot \omega_i, |V_w| \cdot \cos(\alpha_i))} \quad \text{for i: fl, fr, rl and rr}
\] (14)

To complete the vehicle modelling, the linear velocities and lateral slips of wheels are stated as:

\[
V_{wfl} = \left( u - \frac{T_a}{2} \right) i + (v + L_f \cdot r)j
\] (15)

\[
V_{wfr} = \left( u + \frac{T_a}{2} \right) i + (v + L_f \cdot r)j
\] (16)

\[
V_{wrl} = \left( u - \frac{T_a}{2} \right) i + (v - L_r \cdot r)j
\] (17)

\[
V_{wrr} = \left( u + \frac{T_a}{2} \right) i + (v - L_r \cdot r)j
\] (18)
3.3 Accelerator and Brake Pedal Modelling

A simple PID controller has been designed which simulates driver’s behaviours in utilizing accelerator and brake pedal. For this purpose, a fuzzy controller, in SUGINO form, has been designed for each wheel.

\[ T_i = \left( K_p + \frac{1}{k_i} + K_d \cdot S \right) (V_{ref} - V_s) \]

for \( i : fl, fr, rl, rr \) (26)

\( T_i < 0 \rightarrow \text{Braking torque applied to each wheels} \), \( T_i = T_{fl} = T_{fr} = T_{rl} = T_{rr} \)

\( T_i > 0 \rightarrow \text{Accelerating torque applied to the front wheels} \), \( T_i = T_{fl} = T_{fr} T_{rl} = T_{rr} = 0 \)

4. Desired Lane and Yaw Angle Detection

A trained Neuro-Fuzzy network can approximate maps for the model of vehicle’s dynamics. To arrive at a Neuro-Fuzzy network for a given physical model, the constructed network is trained via back propagation using samples generated by simulation of the model. Training procedure requires generating and processing of many samples; hence, it is typically a slow process. Once the network is trained offline; it can be exploited online to produce a variety of fast dynamics. Figure 3 shows the network used for yaw rate reference generation. The network takes three inputs as shown in the figure, where each input has 12 membership functions. The yaw rate, which is considered as output, and all the memberships are assumed as triangular. The network maps the vehicle speed, steering angle and their changes into yaw rate references. The training process of the network is performed using various steering angles including sinusoidal steering and various speeds. Fuzzy rules and properties of membership functions are obtained via the training process. The training process is performed on a high adhesive road surface through which the vehicle’s yaw rate is extracted for the best driving condition, which can be used in all critical conditions as a reference signal. It allows the vehicle to have the same dynamical behaviours on slippery road surfaces, as it has on normal ones.

5. Control Strategy

Regarding the proposed architecture discussed in Section 2, the two main aims which are focused in this paper are as follows:

A. Avoiding wheel lockup, during braking due to operating on slippery road surface or hard braking torque. For this purpose, a fuzzy controller, in SUGINO form, has been designed for each wheel.

B. Keeping vehicle on its desired lane during braking, and for this purpose a sliding mode controller has been designed to achieve separate braking torques for each of the left and right wheels.

5.1 Sliding Mode Controller for ASBS Design

Due to nonlinearity nature of vehicles and necessity of robust behaviour, the sliding mode can be considered as a proper structure of controllers [9]. Indeed, it proves to be a powerful controller for nonlinear dynamics in vehicle controller usages. In [10], a control system designing approach is proposed based on back stepping theory and sliding mode control for bank-to-turn unmanned aerial vehicle. To generate differential braking torque to meet \( e_\psi = \psi_d - \psi = 0 \), the sliding mode control is used [9,11], where sliding surface is defined as:

\[ S = m e_\psi (t + \Delta t) + \frac{d e_\psi (t + \Delta t)}{dt} \] (28)

This surface consists of two terms: weighted error and error change. Comparing the weighted error and the error change a result will be produced which is denoted with an arbitrary positive constant \( m \).

In (28), \( e_\psi (t + \Delta t) \) is the estimated yaw error which can be obtained via the following simple linear estimator:

\[ e_\psi (t + \Delta t) = e_\psi (t) + \frac{d e_\psi (t)}{dt} \Delta t \] (29)
According to the structure of sliding mode controller and using the sliding surface (28), (30) can be expressed as:

$$\Delta \tau_p(t + \Delta t) = \tau(t) \cdot \frac{S}{|S|} = \tau(t) \cdot \text{sgn}(s)$$

(30)

where, \( \text{sgn} \) denotes the sign of \( s \), and \( \Delta \tau_p \) is the difference of the left and the right braking torques which will generate the direct yaw moment; \( \tau(t) \) is the braking torque-demand which is requested from the driver. Since \( \Delta \tau_p(t + \Delta t) \) might oscillate with high frequencies according to the sign of the \( S \), so the following low-pass filter ought to be used:

$$\tau_c \cdot \Delta \tau_p(t + \Delta t) + \Delta \tau_p(t + \Delta t) = \Delta \tau(t + \Delta t)$$

(31)

where, \( \tau_c \) is the time constant of the first order low-pass filter. To avoid or reduce the likelihood occurrence of chattering phenomena, output oscillation frequencies are limited to \( 1/(2\pi \sqrt{\tau_c}) \) Hz by this filter. \( \Delta \tau \) is the filtered torque, which is the difference of the braking torques. The left and the right braking torques can be obtained as:

$$\tau_{\text{Right}}(t + \Delta t) = \frac{\tau(t) + \Delta \tau(t + \Delta t)}{2},$$

$$\tau_{\text{Left}}(t + \Delta t) = \frac{\tau(t) - \Delta \tau(t + \Delta t)}{2}$$

(32)

### 5.2 Fuzzy Controller for ABS Design

Fuzzy logic controllers are amongst powerful controllers in the realm of nonlinear dynamics, which can be mainly categorized into MAMDANI, TAKAGI-SUGINO and TSUKAMOTO types. Here, the second type is considered to be appropriate for the pertinence of the considered issue as well as its advantages, there is no need for separate defuzzification layer, for example [9]. For the design of the antilock braking controller a fuzzy controller with TAKAGI-SUGINO, zero-order form where the output is categorized into MAMDANI, TAKAGI-SUGINO and TSUKAMOTO types. Here, the second type is considered in the realm of nonlinear dynamics, which can be mainly investigated which resulted in reduced online computational burden; where a simulation example of three sensors was used to show the effectiveness of the proposed estimator. The mentioned method could be used for our proposed method, but it has not been investigated in the paper.

#### 5.3 Data Fusion for an Experimental Case

For data fusing purposes, there needed a computer along with related programs and some suitable sensors in order to acquire the required data from the vehicle, which will be further applied to the designed controller. Regarding Fig. 1, and the obtained and extracted formulae throughout the preceding sections, Fig. 5 shows the actuators and the controller. It is noteworthy that, utilization of estimators would lead to less sensors and computation process. In [12], using Kalman filter, a steady-state fusion estimator has been investigated which resulted in reduced online computational burden; where a simulation example of three sensors was used to show the effectiveness of the proposed estimator. The mentioned method could be used for our proposed method, but it has not been investigated in the paper.

### 6. Simulation Results and Comparison

To evaluate the effectiveness of the proposed controller (ALASB), the numerical values of the vehicle model [5]
are listed in Table 2. These parameters corresponded to a mid-size passenger car. In addition, $m$ and $\tau_c$, which are used in the sliding mode controller, are set to 1 and 0.05, respectively.

### 6.1 Braking on $\mu$-Split Road

In this section a braking at the speed of 110 km/h on a $\mu$-split road, comprising dry pavement ($\mu_{\text{peak}} = 0.95$) on the right side and unpacked snow ($\mu_{\text{peak}} = 0.45$) on the left side, has been simulated, where the steer angle is assumed to be zero. The vehicle's speed reduction and its lane are depicted in Fig. 6, which show that the ALASB system has a good stability during braking, and undesired lane changes are so little which can be neglected. Applied braking torques and slips of wheels, have been shown in Figs 7 and 8, respectively.

### Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle total mass</td>
<td>$M_t$</td>
<td>kg</td>
<td>850</td>
</tr>
<tr>
<td>Distance from front axle to CG</td>
<td>$L_f$</td>
<td>m</td>
<td>1.147</td>
</tr>
<tr>
<td>Distance from rear axle to CG</td>
<td>$L_r$</td>
<td>m</td>
<td>1.197</td>
</tr>
<tr>
<td>Track width</td>
<td>$T_a$</td>
<td>m</td>
<td>1.4</td>
</tr>
<tr>
<td>Drag coefficient</td>
<td>$C_d$</td>
<td>N.s/m$^2$</td>
<td>0.41</td>
</tr>
<tr>
<td>Frontal area</td>
<td>$A_F$</td>
<td>m$^2$</td>
<td>1.8</td>
</tr>
<tr>
<td>Lateral area</td>
<td>$A_L$</td>
<td>m$^2$</td>
<td>4.5</td>
</tr>
<tr>
<td>Vehicle inertia about $z$ axis</td>
<td>$I_z$</td>
<td>kgm$^2$</td>
<td>7809</td>
</tr>
<tr>
<td>Wheel’s longitudinal stiffness</td>
<td>$C_x$</td>
<td>N</td>
<td>17,500</td>
</tr>
<tr>
<td>Wheel’s lateral stiffness</td>
<td>$C_y$</td>
<td>N/rad</td>
<td>15,000</td>
</tr>
<tr>
<td>Wheel’s radius</td>
<td>$R_w$</td>
<td>m</td>
<td>0.275</td>
</tr>
<tr>
<td>Wheel’s inertia</td>
<td>$I_w$</td>
<td>Kgm$^2$</td>
<td>3.625</td>
</tr>
</tbody>
</table>

Figure 6. Vehicle’s speed and its lane during braking on $\mu$-split road.

Figure 7. (a) Longitudinal slips of wheels during braking on $\mu$-split road. (b) Magnification of (a) for $5s < t < 5.5s$ for better illustration of differential braking.

### 6.2 Braking and Turning Round on Slippery Road Surface

In this section, simultaneous braking and turning has been simulated, and Fig. 9 shows the vehicle’s speed and steering angle during the simulation. The simulation performed considering the following conditions:

A. Driving on a normal road surface having $\mu_{\text{peak}} = 0.95$. The vehicle lane, in this simulation, has been considered as reference lane which is generated by the trained network via $\Psi_d$.

B. Driving on a road surface with $\mu_{\text{peak}} = 0.95$ for the right wheels and $\mu_{\text{peak}} = 0.45$ for the left wheels, without any controller.
Figure 8. Longitudinal slips of wheels during braking on μ-split road.

C. Driving on a road surface with $\mu_{\text{peak}} = 0.95$ for the right wheels and $\mu_{\text{peak}} = 0.45$ for the left wheels, associated with merely an ABS controller.

D. Driving on a road with $\mu_{\text{peak}} = 0.95$ for right wheels and $\mu_{\text{peak}} = 0.45$ for left wheels, associated with an ALASB controller.

Throughout conditions A–D, it is assumed that the vehicle’s speed and steering angle have been requested as in Fig. 9. Regarding Fig. 10, the vehicle has a good dynamical behaviour on slippery road. In fact, the ALASB controller is a driver assistance system for stability enhancement of vehicle during braking; indicating, that the vehicle has the same behaviour on slippery road surface as it has on normal ones. Figures 11 and 12 show the longitudinal slips and the applied braking torques

6.3 Comparison

In this section, a comparison has been made between the proposed method and a recent braking system given in [5], titled as BBW control system, which is based on the fuzzy controller as shown concisely in Fig. 13.

In the aforementioned research work, antiskid controller was not investigated. The comparison has been made via two simulations. First, a soft braking on μ-split road where wheel lockup has not occurred and, in the second, a hard braking where wheel lockup has taken place.

6.3.1 Soft Braking on μ-Split Road

Braking at the speed of 102 km/h on a μ-split road surface, corresponding to dry pavement ($\mu_{\text{peak}} = 0.95$) on the right side and unpacked snow ($\mu_{\text{peak}} = 0.45$) on the left, has been simulated where the steer angle is assumed to be zero.
The applied braking torques’ resultant is equal to 700 N.m as driver-braking torque demands during 2s. Results of wheels’ slips and the vehicle’s lane are shown in Figs. 14 and 15.

Considering Figs. 14 and 15, the BBW controller has a better response compared to ALASB controller. However, maximum lane change by the ALASB controller is approximately 9 cm.

6.3.2 Hard Braking on $\mu$-Split Road

Applying a braking torque of 2100 N.m as the driver-braking torque demands, the previous simulation has been repeated once more which shows the ALASB controller’s superiority, regarded as a better performance in this case, over the BBW control system. While, in the BBW system the left wheels lockup; typifying its drawback and minute performance facing such kinds of road surfaces. Furthermore, vehicle’s speed reduction will be helpful for ALASB control system due to shirking of wheels lockup likelihood. Moreover, average undesired lane change for BBW control system is about 90 cm while it is 9 cm for the proposed ALASB controller.

7. Conclusion and Recommendation

A novel driver-assistance stabilizer, for brake systems, has been introduced which is based on fuzzy and sliding mode controller for antilock and antiskid braking controls, respectively. The system adjusts four independent braking torques to bring the vehicle back in to the alignment of the driver’s needs during braking. The investigation associated with computer simulations proved the effectiveness

![Controller’s structure proposed in [5]](image13)

Figure 13. Controller’s structure proposed in [5].

![Comparison of vehicle’s lanes](image14)

Figure 14. Comparison of vehicle’s lanes.

![Comparison of wheels’ slips](image15)

Figure 15. Comparison of wheels’ slips.

![Comparison of vehicle’s lanes](image16)

Figure 16. Comparison of vehicle’s lanes.

![Comparison of wheels’ slips](image17)

Figure 17. Comparison of wheels’ slips.
of the proposed control system in the betterment of vehicle performance under severe conditions. Comparing the proposed method with a well-known braking control system (BBW) shows the superiority and better performance of the proposed strategy. Finally, it is recommended, for those research works focusing on control parameter estimation, as discussed in the data fusion section, to reduce number of the required sensors.

References


Biographies

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