

## CONTROL ON THE SAFE DISTANCE IN FRONT OF THE VEHICLE USING BRAKE FUZZY CONTROLLER

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### **Abstract**

In this paper, fuzzy brake controller is proposed. It is build by using the theory of fuzzy sets. The rules base of this controller are based on the previous knowledge and experiences in vehicle field.

The working of controller reduces the vehicle velocity to achieve the safe distance in front between the vehicle and anther vehicle that traveling in front of it. So the controller prevents the slip in the tires during braking.

The velocity error and distance error are used as inputs and brake force as control action output for the controller.

The simulations of fuzzy controller with nonlinear brake vehicle model give acceptable responses for different cases.

### **الخلاصة**

في هذا البحث تم تقديم مسيطر الفرامل المضبضب والذي تم تصميمه باستخدام نظرية المجمامع المضبضبة ومن المعلومات والخبرة السابقة في مجال المركبات تم ايجاد القواعد الاساسية لهذا المسيطر. يعمل المسيطر المقترح على تقليل سرعة المركبة للمحافظة على مسافة الامان بينها وبين المركبة التي تسير امامها وبدون حدوث انزلاق للعجلات اثناء عملية الفرملة. هذا المسيطر يستخدم خطأ السرعة النسبية بين المركبتين وخطأ مسافة الامان كادخال له، اما اخرجه فيكون قوة الفرملة. المحاكاة لهذا المسيطر مع نموذج اللاخطي للمركبة اعطى استجابات مقبولة حتى عند الظروف الصعبة.

## **1- Introduction**

Many control systems are developed and used in the vehicle field to improve the performance of vehicles, reduce the effort of drivers, and so give more safety for passengers and the people that use the road.

The antilock brake system (ABS), electronic brake distribution (EBD), electronic traction system (ETS) and cruise control are some control systems that used in the vehicles in the present time[1].

The fuzzy logic controllers enter forcedly in the vehicle field because it has many good specifications that make the designers prefer it from the classical controllers. The fuzzy controller is more efficient to control on the nonlinear systems and so the behavior of dynamic vehicle systems are nonlinear therefore the using of fuzzy controller gives acceptable performance.

Any computer languages can build the structure of fuzzy controller that means it needs software only; therefore this controller became easy and not expensive. Also the modification and tuning of fuzzy controller is not difficult.

Many researches are presented and developed the fuzzy controllers that used to improve the performance of vehicle. Thomas Hessburg[2] controlled on lateral motion of vehicle during turning a maneuver by fuzzy controller. Mike Bauer[3] presented two fuzzy traction controllers and investigated their effect on longitudinal platoon systems and the resulted indicated to the traction control improve longitudinal platoon performance, especially when icy road conditions exist. Ian Hwa[4] examined the use of fuzzy logic in the control of vehicle steering efforts for purpose of providing the driver with the optimal

road feel and driving comfort at all time. A. sabah[5] developed the automatic brake system for the vehicle by using fuzzy controller which stops the vehicle completely to avoid crashing with any body in front of vehicle. Kenneth[6] uses fuzzy logic controller for the purpose of determining and assigning desired wheel slip for each corner of a vehicle.

The objective of this paper is to develop and simulate brake fuzzy controller, which works to regulate the vehicle velocity by braking in order to keep up the safe separation distance between the back vehicle in front. The nonlinear brake vehicle model is used for simulations.

## **2- vehicle model**

The equation of vehicle motion for longitudinal direction is formed using fig.(1) [7].

$$F_{bf} + F_{br} + f_r mg + R_a \pm mg \sin(\theta) = ma \dots(1)$$

The values of the coefficient of rolling resistance ( $f_r$ ) for passenger car can be calculated from equ.[6]

$$f_r = f_o + f_s \left( \frac{3.6v}{100} \right)^2 \dots(2)$$

Where  $v$  is vehicle speed in (m/sec.) and  $f_o, f_s$  are coefficients depend on the inflation pressure as shown in Fig.(2) [7]. The relations between the  $f_o, f_s$  and tires air pressure are found by curve fitting, therefore the tires air pressure effect is introduced in vehicle model.

The aerodynamic resistance can be calculated from equ.

$$R_a = K_a v^2 \dots(3)$$

Where  $K_a$  is the coefficient of aerodynamic resistance, for passenger car  $K_a = 0.5 \text{ Nsec}^2/\text{m}^2$

Substitution of eqs (2) and (3) into equ.(1) results in the nonlinear differential equation for longitudinal motion (x-direction)

$$F_{bf} + F_{br} + f_0 mg + (f_s (0.036)^2 mg + K_a) v^2 \pm mg \sin(\theta) = ma \quad \dots(4)$$

For the case of the vehicle brake control where the variables of interest are the deceleration,  $a$  ( $=x$ ), velocity,  $v$  ( $=x$ ) and distance,  $(x)$ , the equation of motion (4) become

$$[F_{bf} + F_{br} + f_0 mg + (f_s (0.036)^2 mg + K_a) x^2 \pm mg \sin(\theta)] \frac{1}{m} = x \quad \dots(5)$$

When two vehicles, one of them is front of the another one, the driver in the back vehicle must left a distance ( $d$ ) between two vehicles, this distance is named safe distance which can be calculated from below equ. as shown in Fig.(3).

$$d = d_i + x_2 - x_1 \quad \dots(6)$$

Where  $d_i$  is the initial distance between two vehicles,  $x_1$  is displacement of the back vehicle and,  $x_2$  is displacement of the vehicle in front.

The desired safe distance may be estimated as 1m for 1 km/h of velocity.

Practically, the infrared or ultrasound radar are used as a target sensor in the controlled vehicle to determine the distance between two vehicles and the velocity of vehicle in front[1].

### **3- Brake System Model**

In this paper, the brake model takes into considering the saturation effect of ABS controller in which brake force to the wheels is limited to prescribed wheel slip. The value of saturation effect is different between the front and rear wheels because there

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is load transfer from the rear axle to front axle during braking.

The maximum braking force (saturation effect) on the front and rear axles are given by [7].

$$F_{bf \max} = \mu W_f = \frac{\mu W (l_2 + h(\mu + f_r))}{L} \quad \dots(7)$$

$$F_{br \max} = \mu W_r = \frac{\mu W (l_1 - h(\mu + f_r))}{L} \quad \dots(8)$$

The value of coefficient of road adhesion ( $\mu$ ) is taken 0.9 for dry road and 0.5 for wet road.

Also, to prevent lock wheels, the distribution of braking force between the front and rear wheels must not equal, therefore the proportional of the total braking force on the front and rear axles ( $K_{bf}$ ,  $K_{br}$ ) are introduced in brake model. The ( $K_{bf}$ ,  $K_{br}$ ) are determined by [6]

$$\frac{K_{bf}}{K_{br}} = \frac{l_2 / L + h / L (\mu + f_r)}{l_1 / L - h / L (\mu + f_r)} \quad \dots(9)$$

We can see from equ.(9) the ( $K_{bf}$ ,  $K_{br}$ ) are not constant but they depended on the coefficient of road adhesion ( $\mu$ ) and coefficient of rolling resistance ( $f_r$ ). The coefficient of road adhesion describes the condition of road, dry or wet and coefficient of rolling resistance including the effect of tires inflation pressure.

The simulation dynamics are based on the following assumptions:

- Vehicle dynamics are considered in a one dimension (bicycle model)
- The pitch motion is neglected during braking.
- The vehicle moves on flat road in straight line.- The road surface coefficient is the same for all tires.

### **4- Fuzzy controller**

The intelligent controllers are more effective than others controllers to control on nonlinear system;

therefore, the proposed controller in this paper is fuzzy controller.

The suggested controller works when the distance between two vehicles is less than safe distance, the controller will reduce the speed of controlled vehicle by braking until distance reaches to a safe separation distance, this means the controlled vehicle must have the same speed of vehicle in front.

The suggested controller takes into considering many vehicle parameter variations. The condition between the road and tires is expressed by the value of coefficient of road adhesion, the effect of tires pressure and variation of vehicle mass.

The present fuzzy controller has two inputs, the error of safe separation distance between the vehicle and the vehicle in front and the error of the closing speed of vehicle and it has one out put which is brake force.

The values of fuzzy controller input and outputs are divided to linguistic values based on the previous knowledge and experience in this field.

The distance errors are divided into seven linguistic variables as shown in table (1) and the fuzzy membership function sets for them are shown in figure (4).

The velocity errors are divided into seven linguistic variables as shown in table (1) and the fuzzy membership function sets for them are shown in figure (5).

The brake force is divided into seven linguistic variables. These are shown in table (1) and their fuzzy membership function are shown in figure (6).

These definitions of linguistic variable sets resulted in forty nine if-then type fuzzy inference rules as shown in table (2). To defuzzify the fuzzy control output (brake force) to obtain numerical value of brake force which can be sent to the brake system

Control On The Safe Distance In Front Of The Vehicle Using Brake Fuzzy Controller of vehicle, the center of area method is used. This method is a popular defuzzification strategy [8].

Practically, the signal resulting from the controller is proportional to the hydraulic pressure in the brake system for the vehicle. This signal is brake force. This means

$$P = K_b F_b \quad \dots(10)$$

Where  $P$  is hydraulic pressure,  $K_b$  is brake gain, and  $F_b$  is the brake force which effect in the opposite of vehicle longitudinal direction. The brake gain  $K_b$  is based on the physical dimensions of the hydraulic system and type of the brake [9].

Figure (7) shows the structure of the fuzzy brake controller with the vehicle model.

### **5- Simulations**

The performance of suggested controller is evaluated using the closed loop step response for nonlinear brake model that describing in eqs.(5 to 9) including the road-tire interaction, condition of tires and variation in vehicle mass. The numerical values of constants vehicle that appear in appendix (B) are used.

The desired values for velocity different is zero and for safe distance in mete is resulting from the controlled vehicle velocity in meter per second multiply 3.6 as shown in block diagram of fuzzy controller with vehicle model, figure(7)

Four cases are taken to exam the performance of fuzzy brake controller.

#### **Case-1**

The controlled vehicle is traveling in 50m/h on dry road and suddenly pears anther vehicle in front with 20km/h velocity. The separation distance is 30m, this distance is less than safe separation distance 50m.

The fuzzy controller reduces the speed of controlled vehicle to 20 km/h at 12 second as shown in figure (8) and

the distance between the vehicles become 20m shown in figure (9), this is safe distance.

Also the case-1 is implemented when the road is wet and the controller gives acceptable performance as shown in figures (8) and (9).

### **Case-2**

In this case the different between the velocities of vehicles are very large and the initial separation distance is small. The controlled vehicle and the vehicle in front are traveling in 90km/h and 10 km/h respectively on dry road. The initial distance between them is 50 m which is less than safe separation distance 90 m.

The fuzzy controller reduces the speed of controlled vehicle to 10km/h at 15 second as shown in figure (10) and the distance between the vehicles become 6.5 m not 10 m as shown in figure (11), this means there is error steady state equals 3.5m.

### **Case-3**

This case tests the performance of fuzzy controller when the mass of vehicle is changing. The initial conditions are: the velocity of controlled vehicle is 100km/h, the velocity of vehicle in front is 50km/h and the separation distance is 80m.

The responses of the velocity and distance are shown in figures (12) and (13) respectively when the mass is 1200kg and 1700kg. From these figures, we can see the fuzzy controller achieved the safe distance 50m and velocity 50 km/h.

The acceleration (here deceleration) is one of the important values that indicate if slips in tires are happened or not. When the deceleration is less than critical deceleration ( $a = \mu g$ )[7], the slip in the tires are not happened.

### **Case-4**

Final case tests the performance of fuzzy controller when the vehicle travels up the incline,  $\theta = 10^\circ$ , with initial velocity 60km/h, initial safe distance 50 m and the velocity of vehicle in front 40km/h the fuzzy controller reduces the speed of controlled vehicle to 40km/h at 10 second as shown in figure (14) and the distance between the vehicles become 38m shown in figure (15). From the distance response it can be seen, the distance does not reach to the exact value of safe distance (40m). the steady-state error in this case is about (2m) and this value may be acceptable practically.

It is important to see that the effect of the weight affects on the brake model as disturbance. When the vehicle travels up the incline, the weight effect works against the brake force, therefore the controller must be more robust to give acceptable performance.

Figure (16) shows the response of deceleration for previous cases. The values of deceleration are not exceeding the critical deceleration ( $8.8\text{m/sec}^2$ ), this indicates to no slip in the tires.

## **6- Conclusions**

The suggested controller in this paper was implemented by using the fuzzy logic theory. It is used with a nonlinear brake vehicle model to achieve the safe distance in front vehicle. Many variations in vehicle parameters were taken in considering such as the condition between the road and tires, effect of tires pressure and variation of vehicle mass.

The results of the fuzzy controller simulations give acceptable responses for velocity and safe distance for different cases until in worst case. The fuzzy controller reduces the velocity without occurring

slip in tires therefore the vehicle does not loss its stability and its direction.

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### Appendix-A

#### Nomenclatures

$a$  = deceleration (m/sec<sup>2</sup>)  
 $d$  = distance between two vehicles (m)  
 $d_i$  = initial distance between two vehicles (m)  
 $F_{df}$  = front brake force (N)  
 $F_{bf}$  = front brake force (N)  
 $f_r$  = coefficient of rolling resistance.  
 $f_o, f_s$  = coefficients depend on the inflation pressure.  
 $g$  = acceleration of gravity (m/sec<sup>2</sup>)  
 $h$  = height of the center of mass (m)  
 $L$  = vehicle track (m)  
 $l_1$  = length from mass center to front axle (m)  
 $l_2$  = length from mass center to rear axle (m)  
 $K_a$  = coefficient of the aerodynamic resistance (Nsec<sup>2</sup>/m<sup>2</sup>)  
 $K_b$  = brake gain (Pa/N)  
 $m$  = vehicle mass (kg)  
 $R_a$  = aerodynamic resistance (N)  
 $v$  = vehicle velocity (m/sec.)  
 $x_1$  = displacement of the back vehicle (m)  
 $x_2$  = displacement of the vehicle in front (m)  
 $W$  = vehicle weight (N)  
 $W_f$  = normal load on the front axle (N)  
 $W_r$  = normal load on the rear axle (N)  
 $\theta$  = angle of the slop with the horizontal (deg)  
 $\mu$  = coefficient of road adhesion

### Appendix-B

#### Physical parameters of the vehicle

$m = 1200\text{kg}$   
 $L = 2.5\text{m}$   
 $l_1 = 1\text{m}$   
 $l_2 = 1.5\text{m}$   
 $K_a = 0.5 \text{ Nsec}^2/\text{m}^2$   
 $h = 0.6\text{m}$   
 $\mu = 0.9$  for dry road,  $0.5$  for wet road