Design for the Predictor of the Emergency Braking System Based on Fuzzy Algorithm

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***Abstract*—Currently, many vehicle manufacturers and academic researchers have been focusing on researching and developing the active safety systems to reduce collisions between the eco car and front obstacles based on the radar technologies. Therefore, they actually have limitations that whose systems are lack of considering about driver's intentions. In this paper, we propose the predictor of the Emergency Braking System (EBS), which adapts to driver's intentions. For design of such system, we mainly made fuzzy predictor and fuzzy Driver Intention Reader (DIR), using fuzzy algorithm. And, we simulated several typical situations to evaluate the system performance. As a result, we have confirmed the functionality and reliability of the system logics.**

***Index Terms*—EBS, fuzzy predictor, fuzzy driver intention reader, active safety system, critical distance calculator**

I. Introduction

Nowadays, the amount of vehicles is increasing consistently and the safety drive environment has become a big issue in the world. At the same time, researches of the integrated vehicle safety control systems have been ongoing for protecting drivers and pedestrian based on sensor fusion technology [1].

For designing the predictor of the emergency braking system as an active safety system, we decided to apply a long-range radar sensor launched by Bosch to measure the distance between the eco car and front obstacles after comparison [2]. Fig. 1 shows the system design concept. The system operates functions reasonably with driver's reactions about collision risks. Main system functions include stand-by, warning, partial brake and full brake. These functions will be operated with different levels depending on driver's reaction about collision risks such as careless, deceleration and steering etc. Also, the system calculates critical distance to predict the emergent time based on the eco car speed and front obstacles speeds.

Vehicle parameters and brake system model are presented in Section II, the system control logic is presented in Section III, the simulation results with typical situations are presented in Section IV and conclusions of the work are given in Section V.

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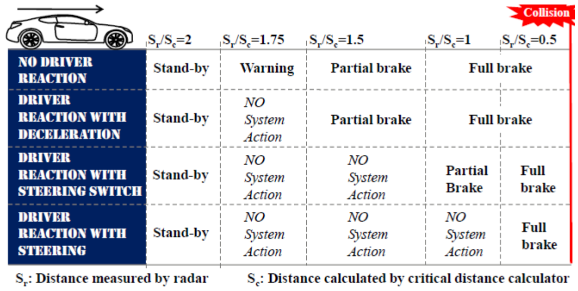

Figure 1. Predictor of emergency braking system design concept

II. System Model

Fig. 2 shows the full vehicle model we have chosen whose parameters were set based on a real vehicle.

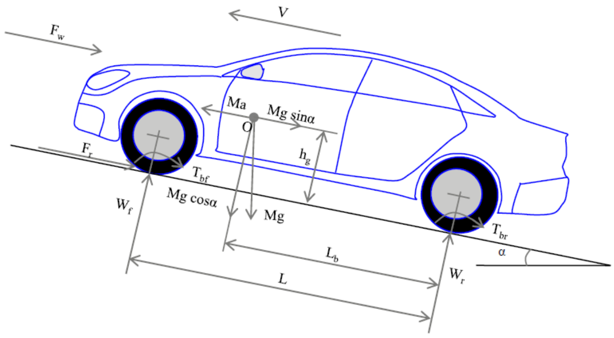

Figure 2. Full vehicle model [3]

As shown in Fig. 2, vehicle will be affected not only by brake torque but also by rolling resistance (F_r), aerodynamic drag (F_w) and hill climbing resistance (F_g) [3]. We have considered all main factors of driving environment to build the vehicle model.

However, we focused on a quarter car model to design the active safety system as shown in Fig. 3, and assumed that this wheel is one of front wheels. So, we can obtain these equations as follows [3]:

$$\sum F = ma = -F_{bf} - F_g - F_w - F_r \tag{1}$$

$$F_{bf} = \frac{1}{2}\mu(\lambda)W_f \tag{2}$$

$$W_f = \frac{Mg(L_b + h_g j / g)}{L} \tag{3}$$

$$F_g = mg\sin\alpha \tag{4}$$

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$$F_w = \frac{1}{2}\rho A_f C_D (V_v - V_w)^2 \tag{5}$$

$$F_r = mg0.01(1+\frac{V}{160})\cos\alpha \tag{6}$$

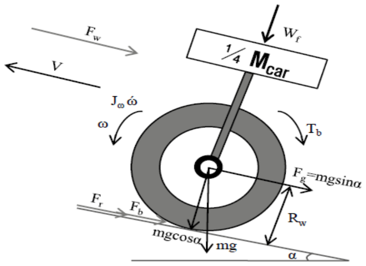

Figure 3. 1/4 car braking system model [3], [4]

Equation (1) is the vehicle acceleration and where ΣF is total resistance, m is the mass of a quarter vehicle, a is the vehicle acceleration rate, F_{bf} is the braking force on one front wheel calculated by (2), F_g is the hill climbing resistance calculated by (4), F_w is the aerodynamic drag calculated by (5), F_r is the rolling resistance calculated by (6). In (2), $\mu(\lambda)$ is the friction coefficient between tire and road, W_f is the normal load on the front axle calculated by (3). In (3), M is the total mass of the vehicle, g is the gravitational acceleration, j is the vehicle deceleration rate and has the opposite sign of a, L_b is the length from the rear axle to the gravity axle, h_g is the height from the gravity center to ground. In (4), α is the road angle. In (5), ρ is the air density, A_f is the vehicle front area, V_v is the eco vehicle speed, V_w is the wind speed and assumed to be zero.

$$J_w \dot{\omega} = -T_{bf} + F_{bf} R_w - (F_g + F_w + F_r) R_w \tag{7}$$

TABLE I. VEHICLE PARAMETERS

Parameters	Values
Vehicle mass(M)	1300kg
¼ M=m	325kg
Wheelbase(L)	2.8(m)
Lb	1.7m
hg	0.7m
Effective radius of tire(Rw)	0.41m
Moment of inertial of wheel(Jw)	2kg.m2
Air Density(ρ)	1.205kg/m3 (20℃)
Vehicle Front Area(Af)	2.2 (m2)
Coefficient of Aerodynamic Resistance(CD)	0.42
Friction Coefficient Range (μ(λ))	0.07~0.9
Gravitational Acceleration (g)	9.8 m/s2
Velocity of Wind(Vw)	0 km/h

Equation (7) is the rotational dynamics of the wheel used for calculating wheel speed, and where J_w is the moment of inertial of wheel, $\dot{\omega}$ is the wheel angular acceleration rate, T_{bf} is the brake torque of one of front wheels, R_w is the effective radius of tire [4]. All the parameters used in above equations are shown in Table I.

III. CONTROL SYSTEM

As shown in Fig. 4, the predictor of emergency braking system consists of fuzzy predictor, fuzzy driver intention reader, critical distance calculator. This system decides when to prepare full brake, warn to driver about collision risk, and support partial brake and full brake automatically via fuzzy predictor based on the driver's intentions and distance analysis.

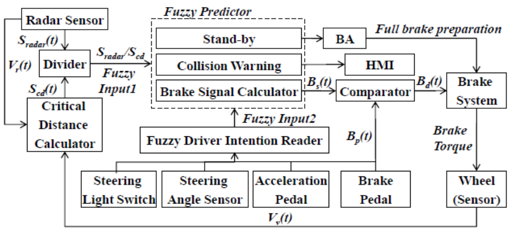

Figure 4. The predictor of emergency braking system structure

A. Fuzzy Predictor

As a main part of system, fuzzy predictor outputs full brake stand-by signals, collision warning signals, brake signals according to situations analyzed by fuzzy driver intention reader and critical distance calculator.

The fuzzy logic consists of three parts: fuzzifier, inference engine and defuzzifier [5], [6]. In the fuzzy predictor, first, the fuzzifier converts the values of measured distance (S_{radar}) divided calculated critical distance (S_{cd}), the value driver intention and EBS control signal to linguistic values as shown in Fig. 5, 6, 7; second, the inference engine figures out the fuzzy output using fuzzy rules created by tuning based on safety assurance as shown in TABLE II; finally, the defuzzifier calculates the emergency braking system control signals using the centroid method [7].

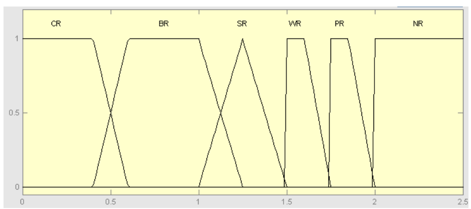

Figure 5. S_{radar}/S_{cd} fuzzy input membership function

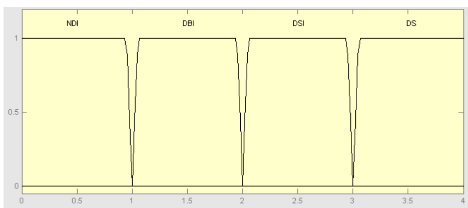

Figure 6. Driver intention fuzzy input membership function

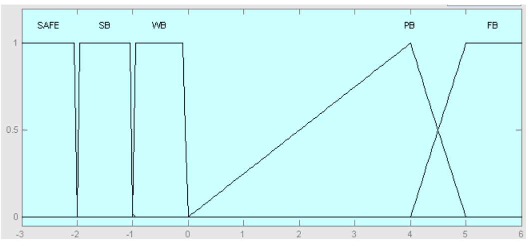

Figure 7. EBS control signal fuzzy output membership function

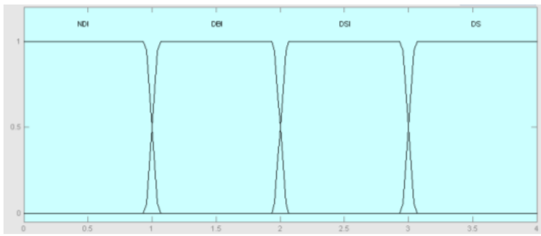

Figure 11. Driver intention fuzzy output membership function

TABLE II. FUZZY PREDICTOR'S FUZZY RULES

DI \ Sr/Sc	**CR**	**BR**	**SR**	**WR**	**PR**	**NR**
NDI	FB	FB	PB	WB	SB	SAFE
DBI	FB	FB	PB	SAFE	SB	SAFE
DSI	FB	PB	SAFE	SAFE	SB	SAFE
DS	FB	SAFE	SAFE	SAFE	SB	SAFE

TABLE III. FUZZY DRIVER INTENTION READER'S FUZZY RULES

Deceleration	**Decel**		**Accel**	
SS \ SA	**CR**	**BR**	**SR**	**WR**
NDI	DBI	DS	NDI	DS
DBI	DSI	DS	DSI	DS

B. Driver Intention Reader

Similar to above procedure, in the driver intention reader, first, the fuzzifier converts the signals from brake pedal sensor, acceleration pedal sensor, steering light switch and steering angle sensor, also driver intentions to linguistic values as shown in Fig. 8, 9, 10, 11; second, the inference engine figures out the fuzzy output using fuzzy rules created based on driving common sense as shown in TABLE III; finally, the defuzzifier calculates the values of the driver intention using the centroid method [7].

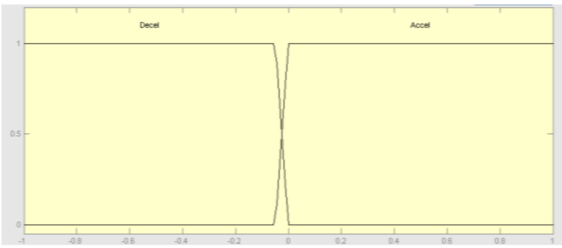

Figure 8. Deceleration fuzzy input membership function

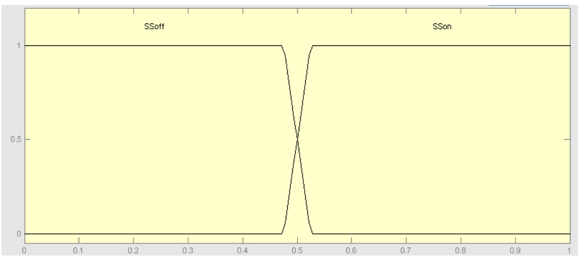

Figure 9. Steering switch fuzzy input membership function

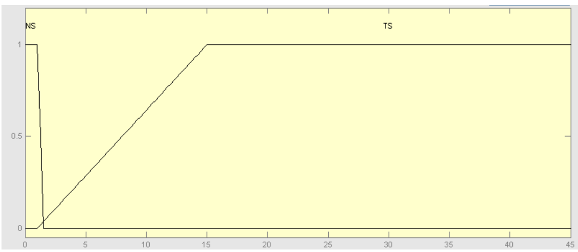

Figure 10. Steering fuzzy input membership function

C. Critical Distance Predictor

The critical distance predictor calculates the braking distance according to the eco car speed and obstacle's moving speed continuously. The work of brake force will change the system energy, mainly the kinetic energy. However, the system energy (E_{total}) can't be conserved during vehicle braking because a lot of energy will be converted to the heat energy (E_h) and lost. By simulation and using the interaction formulas of work and energy, we have confirmed that about 30% system energy would be lost (8). Finally, S_{cd} is derived as (9)

$$F_{bf} S_{sd} = E_k + E_h (E_h = 30\% E_{total}) \tag{8}$$

$$S_{cd}(t) = \frac{0.7(\frac{1}{2} m V_t(t)^2 - \frac{1}{2} m V_v(t)^2)}{-\frac{1}{2}\mu(\lambda) W_f - mg \sin\alpha} + S_{offset} \tag{9}$$

where $V_t(t)$ is the target obstacle speed calculated by (10), S_{offset} is the safety offset distance used for leaving minimum distance from front obstacles when the eco car stopped. In this paper, S_{offset} was set by 5m and $\mu(\lambda)$ was assumed as a constant(0.9).

$$V_t(t) = V_v(t) - V_r(t) \tag{10}$$

In the equation (9), $V_r(t)$ is the relative speed measured by radar sensor.

IV. SIMULATION RESULT

A. Case 1: Driver's Careless Driving with Upcoming Collisions

The eco car is approaching a stationary obstacle with 100*km/h* speed which is initially 250m far from the eco car. The driver doesn't react about potential collision risk at all. In this case, the system will output stand-by signal to prepare full brake, give warning signal to let driver know about the dangerous situation, support partial brake and full brake automatically as shown in Fig. 12, and avoid upcoming collision as shown in Fig. 13. The result shows that the system operated its functions when the distance was close to critical distance and stopped car before collision.

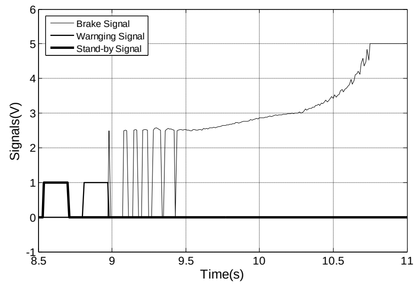

Figure 12. System operation with driver’s full careless

B. *Case 2: Driver’s Deceletion Intention with Upcoming Collision but Braking Not Enough*

On the same situation with case 1, differently the driver has found the obstacle and tried to brake but not enough. In this case, the system would prepare full brake

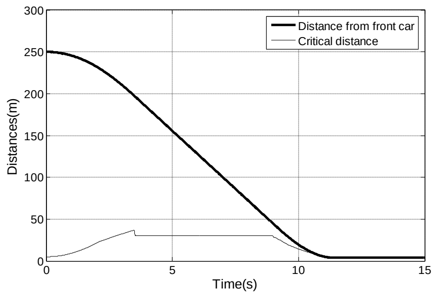

Figure 13. Distance Changes with the system operation

and assist driver to brake without warning as shown Fig. 14 and choose the brake signal generated by the predictor of the emergency braking system as brake command. The result shows that the vehicle is stopped safely as shown in Fig. 15.

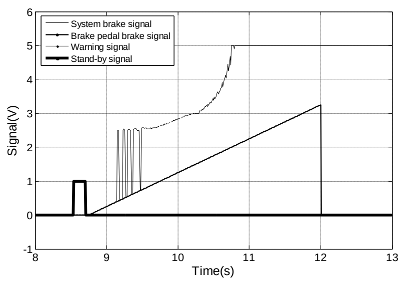

Figure 14. System operation with driver’s insufficient brake

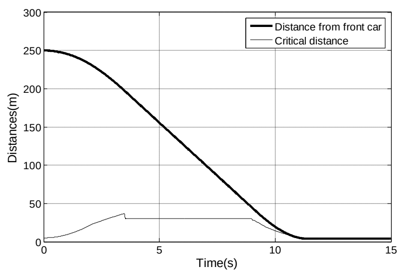

Figure 15. Distance changes with the system operation

C. *Case 3: Driver’s Steering with Upcoming Collision*

On the same situation with case 1, differently the driver has found the obstacle and circumvented it through steering and drive into another road with no car in front. In this case, the system just gave stand-by signal to prepare full brake as shown in Fig. 16. As a result, the distance from front car became 250m after steering because the radar measurement range is 0.5m~250m as shown in Fig. 17.

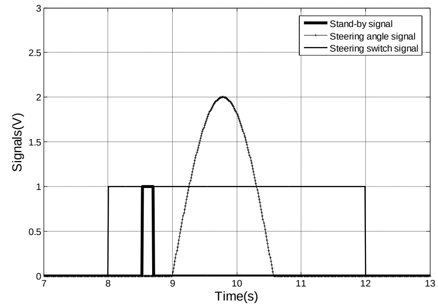

Figure 16. System operation with driver’s insufficient brake

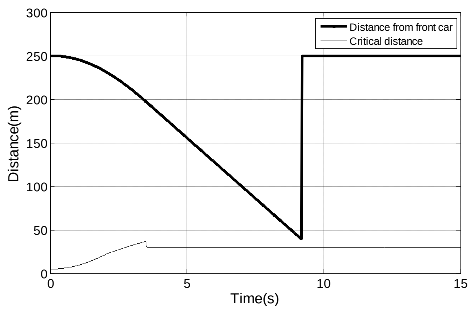

Figure 17. Distance changes with the system operation

V. Conclusions

In this research, we proposed the predictor of emergency braking system which is designed ergonomically. The simulation result shows that the system operates the safety functions adapt to various driver intentions and is able to avoid collisions.

Our next goal is to develop the intelligent active safety system which adapts to not only driver reactions also the uncertain drive environment.

In the future work, we will develop the road friction coefficient estimator combined ABS function and to upgrade the system so that it can adapt to changing road conditions also design fault tolerant control logic for critical sensors such as a radar because this kind system depends on the sensor fusion technology.

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