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.

II. SYSTEM MODEL

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

As shown in Fig. 2, vehicle will be affected not only by brake torque but also by rolling resistance (F_r), aerodynamic drag (F_d) 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]:

\[
\sum F = ma = -F_{gf} - F_g - F_w - F_r \quad (1)
\]

\[
F_{gf} = \frac{1}{2} \mu (\lambda) W_f \quad (2)
\]

\[
W_f = \frac{Mg(I_h + h \cdot f / g)}{L} \quad (3)
\]

\[
F_g = mg \sin \alpha \quad (4)
\]
Equation (1) is the vehicle acceleration and where \( \Sigma F \) 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), \( F_r \) 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, \( \dot{a} \) 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), \( \alpha \) is the road angle. In (5), \( \rho \) 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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle mass (M)</td>
<td>1300 kg</td>
</tr>
<tr>
<td>( \frac{1}{4} M = m )</td>
<td>325 kg</td>
</tr>
<tr>
<td>Wheelbase (L)</td>
<td>2.8 (m)</td>
</tr>
<tr>
<td>Lb</td>
<td>1.7 m</td>
</tr>
<tr>
<td>hg</td>
<td>0.7 m</td>
</tr>
<tr>
<td>Effective radius of tire (Rw)</td>
<td>0.41 m</td>
</tr>
<tr>
<td>Moment of Inertial of Wheel (Jw)</td>
<td>2 kg.m2</td>
</tr>
<tr>
<td>Air Density (( \rho ))</td>
<td>1.205 kg/m3 (20°C)</td>
</tr>
<tr>
<td>Vehicle Front Area (A_f)</td>
<td>2.2 (m²)</td>
</tr>
<tr>
<td>Coefficient of Aerodynamic Resistance (CD)</td>
<td>0.42</td>
</tr>
<tr>
<td>Friction Coefficient Range (( \mu(\lambda) ))</td>
<td>0.07–0.9</td>
</tr>
<tr>
<td>Gravitational Acceleration (g)</td>
<td>9.8 m/s²</td>
</tr>
<tr>
<td>Velocity of Wind (V_w)</td>
<td>0 km/h</td>
</tr>
</tbody>
</table>
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].

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 ($E_{\text{total}}$) 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, $S_{\text{cd}}$ is derived as (9)

$$F_{bf} S_{cd} = E_k + E_h (E_h = 30\% E_{\text{total}})$$  \hspace{1cm} (8)

$$S_{cd}(t) = 0.7 \left( \frac{1}{2} m V_r(t)^2 - \frac{1}{2} m V(t)^2 \right) - \frac{1}{2} \mu(\lambda) W_f - mg \sin \alpha + S_{\text{offset}}$$  \hspace{1cm} (9)

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

$$V_r(t) = V_c(t) - V_s(t)$$  \hspace{1cm} (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 100km/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,
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.

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.

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 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.

ACKNOWLEDGMENT

The authors gratefully acknowledge the useful information from previous Korea government project named ‘Development of Integrated X-by-Wire System with Information Fusion of Surrounding and Vehicle Sensors’.
REFERENCES


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