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Study the Influence of Distance in Artificial Potential Field (APF) for Autonomous Emergency Braking System (AEB) on Longitudinal Motion

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Abstract. Autonomous Emergency Braking (AEB) is one of the common control systems used by the vehicle in order to avoid the collision from the obstacle. AEB performance optimize mostly on dry road surface at low and medium speed. The slip tire model was derived in this paper in order to find the coefficient of road friction. The tire-road friction coefficient is used for the braking limit which is 450 N.m. In order to increase the ability of an AEB during presence of obstacle in front of the vehicle, combination of Time-to-Collision (TTC) and artificial potential field (APF) are proposed in this study. When the APF value was surpassed the threshold distance, the AEB will activate by itself. The limit for APF was designed based on assuming the dry road friction (0.9) condition and with present of static obstacle in front of the vehicle in longitudinal lane. Thus, the AEB system was designed considering on the dry road friction condition, time for Front Collision Warning (FCW)as well as Braking was included for the limit APF is developed. The combination of an additional distance with the maximum safety distance in the APF system will create the minimum safe distance from obstacle which is in the range of 2.0 meter after the vehicle stop entirely. The additional distance is influence by the product of the constant time setting which is t_s1 and t_s2 with current velocity. Then, the simulation results show that the proposed control strategy can adapt to the dry tire-road friction coefficient on the road.

1. INTRODUCTION

Nowadays, the capability to helps the human constraints during driving period in order to reduce road disaster is one of the stimulants of the autonomous vehicle's development recently. Almost 1.2 million deaths exist because of road accidents globally and it is assumed to boost in numbers by 2030. Advanced Driver Assistance Systems (ADAS) is, in this manner, created to ensure to protect the road user ADAS consists of Adaptive Cruise Control, Autonomous Emergency Braking, Anti-lock Braking System and many more as a merger of several complex system[1]. Advanced Driver Assistance Systems (ADAS) is an active safety system to prevent the collision by assisting the driver in certain conditions[1].

Autonomous Emergency Braking (AEB) is one of intermediate ADAS to maintain a distance or avoid from having collision[1].

The ability of the AEB system can be improve by integrate the system with artificial potential field (APF) risk assessment[2-4]. The fundamental idea is that the host vehicle gets attractive energy from the objective point and aversion from the obstacle and keeps away from crash to arrive at the objective position under the resultant force[5, 6]. Besides, the artificial potential field has the favour of limited amount of arithmetic and smoothness of the planned path[6]. The resultant force occurs around the obstacle when the spacing headway of the host vehicle cross the border of the maximum safety distance from the obstacle[7].

Even though the load of commercialized an AEB system, near miss accident still happens, where the distance of the host vehicle is too close to the obstacle[5]. So, to avoid this phenomenon, the enhancement of the AEB product which acknowledge and manage the safe distance towards the collision point is develop. The minimum safety of the vehicle after fully stop is around 2.08 to 3.3 m from the obstacle[8]. Subsequently, conventional Autonomous Emergency Braking System (AEB) have limitation in avoiding collision when the vehicle moves in medium and high speed[5]. This paper aim to do analysis the distance of an AEB activation at each point of the phase; front collision warning and full braking in order to make sure the host vehicle stop entirely 2.0 m from the obstacle. The combination of the additional distance; the production of constant time setting with current velocity, with maximum safety distance in the Artificial Potential Field System (APF) will directly increase or decrease the initial distance of each phase of an AEB activation and affect the minimum safety distance of the vehicle after entirely stop.

2. VEHICLE MODEL

A simplified vehicle dynamics model is developed in this paper to analyse the vehicle dynamics behaviour. Figure 1 shows a simplified model comprises of longitudinal model[9].
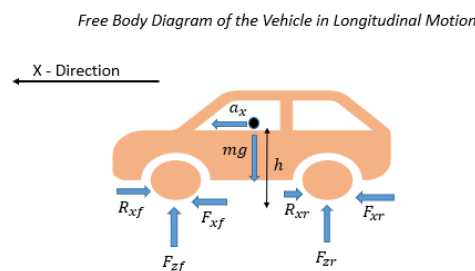

Figure 1. Analysis in Longitudinal Motion of Vehicle Model

Table 1. Specification of the Vehicle

Details	Symbol	Value	SI unit
Mass (Kerb Weight)	m	1330	kg
Center of gravity (c.g) length towards frontal part	Lf	1.107	m
Center of gravity (c.g.) length towards rear part	Lr	1.643	m
Height of center gravity	h	0.479	m
Effective radius of the tire	r_{eff}	0.393	m

3. LONGITUDINAL DYNAMIC MODEL

In the numerical analysis, the equalization of the forces applied on the vehicle is considered. Then, the vehicle is expecting driving on a level and straight street. By assuming the force at left and right tires are same, a bicycle model is used in the analysis. The linear longitudinal forces are expressed follows:

$$ma_x = F_{xf} + F_{xr} - R_x - D_a V_x^2 \tag{1}$$

After balancing the moment with respect to contact points between tires and surface, the normal forces exerted on front and rear tire could be composed as in equation (2) and equation (3)[9]:

$$F_{zf} = (mgL_r - ma_x h - D_a V^2 h_a) / (L) \tag{2}$$

$$F_{zr} = (mgL_f + ma_x h + D_a V^2 h_a)/ (L) \tag{3}$$

Where m is the total mass of the vehicle, a_x is the longitudinal acceleration/deceleration, F_{xf} and F_{xr} are the front and rear wheel traction/braking forces, $R_x = R_{xf} + R_{xr} = C_{roll}mg$ is the rolling resistance force with C_{roll} being the rolling resistance coefficient, D_a is the aerodynamic drag force constant which is in small value and assume to be zero. V_x is the longitudinal velocity. Let L_f be the distance from *c.g.* to the front axle; L_r the distance from *c.g.* to the rear axle and $L = L_f + L_r$ be the wheelbase of the vehicle. The nonlinear longitudinal forces using Dugoff's tire model are expressed as in equation (4)[9]:

$$F_x = C_\sigma \frac{\sigma_x}{1+\sigma_x} f(\lambda) \tag{4}$$

$$f(\lambda) = \begin{cases} (2 - \lambda)\lambda, & \lambda < 1 \\ 1, & \lambda \geq 1 \end{cases} \tag{5}$$

$$\lambda = \frac{\mu F_z (1+\sigma_x)}{2[(C_\sigma \sigma_x)^2 + (C_a \tan(a))^2]^{1/2}} \tag{6}$$

$$\mu_{brk} = -1.15k \{e^{-35\sigma_x} - e^{-0.35\sigma_x}\} \tag{7}$$

where σ_x be the longitudinal slip ratio of the tire under consideration and the longitudinal tire stiffness by C_σ. F_z is the vertical force on the tire while μ is the tire-road friction coefficient and k is the parameter of the road condition. The longitudinal slip ratio during braking is defined as in equation (8)[10] :

$$\sigma_x = \frac{V_x - r_{eff}\,\omega_w}{V_x} \tag{8}$$

Let r_{eff} be the effective radius of the tire and V_x as the longitudinal velocity while ω_w act as a rotational velocity of the tire. The equation for the decelleration, a of host vehicle with considering the tire-road friction coefficient is expressed as in equation (9) :

$$a = F_x\,/\,m \tag{9}$$

Where m is a mass of the vehicle and F_x is the nonlinear longitudinal force.

3.1 Autonomous Emergency Braking (AEB) System Algorithm

Autonomous emergency braking system is a system in the vehicle for executing the brake when the sensor detects the obstacle in front of the host vehicle[11, 12]. AEB is a system which helps the vehicle to avoid the collision by execute an emergency braking during appearance of the static obstacle[11]. The flow of the system is quite different with a conventional AEB. Assuming an obstacle occur in front of a vehicle within the width of the vehicle; then, the collision decision is simplified as longitudinal collision prediction using an Artificial Potential Field (APF) as shown in Figure 2. The system will be turned on when the value of APF violated the threshold distance between the vehicle and obstacle.
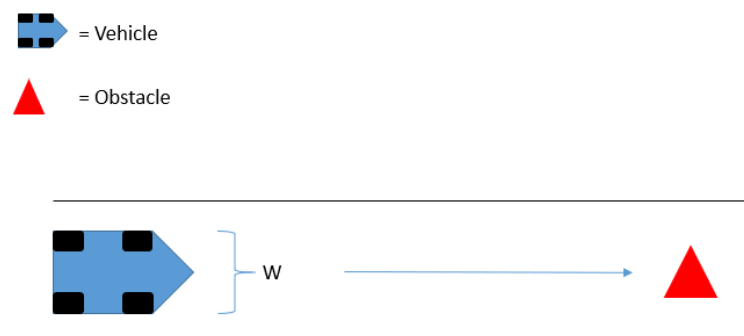

Figure 2 Driving scenario during presence of static obstacle

3.2 Time to Collision Risk Assessment

The time to collision (TTC) is defined as the time that a driver can use to reduce the speed of a vehicle by braking to avoid collision with the front target. The larger the TTC value is, the lower the risk of a collision will be, and vice versa. The evaluation of the TTC is basically from the kinematic model. Besides, the time to collision, TTC is calculated by deriving the equation of the kinematic model when the host vehicle approaches the obstacle as express in equation (10)[4, 13]:

$$|p| = \begin{cases} -vt & , \quad a = 0 \\ -vt + \frac{1}{2}at^2 & , \quad a \neq 0 \end{cases} \tag{10}$$

The time to collision can be obtained by rearranged the equation of kinetic model as shown in equation (11):

$$|TTC| = \begin{cases} \dfrac{-v \pm \sqrt{v^2 + 2pa}}{a}, & v \geq 0 \; and \; a < 0 \end{cases} \tag{11}$$

3.3 Artificial Potential Field

The philosophy of the APF calculation can be schematically depicted in accompanying manners. The host vehicle moves in a power field. The location to be arrived is an attractive pole, $U_{goal}(x)$ for the end effector and obstacle, $U_{obs}(x)$ are repulsive range for the host vehicle are expressed as in equation (12)[6]:

$$U_{art}(x) = U_{goal}(x_d) + U_{obs}(x) \tag{12}$$

Let be ρ_r is the spacing headway of the vehicle and n represent the repulsive gain coefficient. The ρ_{or}, is a given point in the closeness to the obstacle. The potential field occur when the object and obstacle follow this condition ($\rho_r \leq \rho_{or}$) [14]. The repulsive force equation was derived and shown as in equation (14)[14].

$$F_{rep}(X) = \begin{cases} n \left(\dfrac{1}{\rho_r} - \dfrac{1}{\rho_{or}}\right)\dfrac{1}{p_r^2}, & \rho_r \leq \rho_{or} \\ 0, & \rho_r > \rho_{or} \end{cases} \tag{14}$$

3.4 Design of Vehicle Conditional Artificial Potential Field

The Vehicle Conditional Artificial Potential Field (VC-APF) is diverse from the conventional APF and will design only when condition is achieved, which is an AEB system will execute when the vehicle detects an obstacle in longitudinal lane. The smaller the space between the autonomous vehicle and the obstacle, the more repulsive force will be appeared centre on the obstacles. The manipulated range of the repulsion field is ρ_{or} and is related to the speed and the maximum deceleration of the autonomous vehicle, and the relation is explicit by equation (15)[7].

$$\rho_{or} = d_0 + (v_c \times TTC) + \frac{v_c{}^2}{2a_{max}} \tag{15}$$

Where ρ_{or} represents the safe distance while driving, and d_0 represents the minimum safe distance after the vehicle stop. TTC is the time headway of the vehicle to the obstacles, and v_c represents the current speed of the autonomous vehicle while a_{max} represents the maximum deceleration of the vehicle [7]. The value of repulsion force depends on each phase of threat level which is expressed by Equation (16) to equation (18).

Full braking;

$$F_{rep}(X) = \frac{1}{2}n\left(\frac{1}{\rho_r} - \frac{1}{d_0 + \left((v_c \times TTC) + \frac{v_c{}^2}{2a_{max}}\right)}\right)\frac{1}{\rho_r{}^2} \tag{16}$$

$$if, \quad \rho_r \leq \rho_{or} - v_c \times t_{s1}$$

Warning Signal.

$$F_{rep}(X) = \frac{1}{2}n\left(\frac{1}{\rho_r} - \frac{1}{d_0 + \left((v_c \times TTC) + \frac{v_c{}^2}{2a_{max}}\right)}\right)\frac{1}{\rho_r{}^2}$$

$$if, \quad \rho_{or} - (v_c \times t_{s1}) \leq \rho_r \leq \rho_{or} + (v_c \times t_{s2}) \tag{17}$$

No signal.

$$F_{rep}(X) = 0$$

(18)

$$if, \quad \rho_r > \rho_{or} + (v_c \times t_{s2})$$

4. RESULTS AND DISCUSSION

The Potential Field profitably present threat assessment in relationship to the relative distance between host vehicle and obstacle data, provided by the frontal sensor. As shown, the threat assessment field of an AEB start to give warning signal at certain value depends on the velocity of the vehicle and repulsive force start to produce subsequently give braking after the vehicle enter the braking phase. The AEB system activate the desired braking torques, as it reaches maximum torque braking which is 450 N.m and the vehicle will stop entirely after execution of the braking is in the range of 2 m from the obstacle. The stopping distance of the vehicle directly influence by the combination of the additional distance with the maximum safety distance of the APF system. The additional distance data is consisting of the production of the vehicle current velocity, v_c with constant time setting which are t_{s1}, and t_{s2}. Table 2 below shows that all important result that have been recorded during the simulation. Next, the graph in Figure 3 and 4 for (a), (b), (c), (d), (e) shows that the condition of the vehicle which is in varies current velocity, v_c = 45 and 65 km/h and simulate at same initial relative distance of the vehicle from the obstacle which is at Pr = 250 m.

Table 2. Result of the Simulation of an AEB system

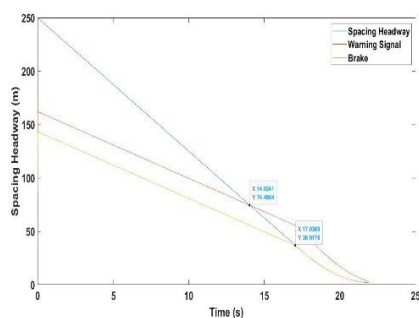| Velocity of vehicle (km/h)	45	65
Torque for braking (N.m)	450	450
Distance from obstacle when vehicle enter warning signal phase (m)	74.49	130.46
Distance from obstacle when vehicle enter braking phase (m)	36.91	76.10
Time setting, t_{s1} (s)	0.255	0.255
Time setting, t_{s2} (s)	1.245	1.245
Minimum safety distance after braking (m)	2.0	2.0

Velocity of the vehicle = 45 km/h

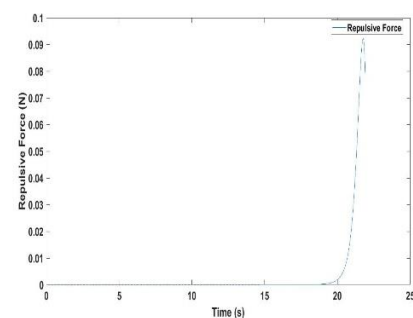**Figure 3 (a)** Point of activation an AEB system
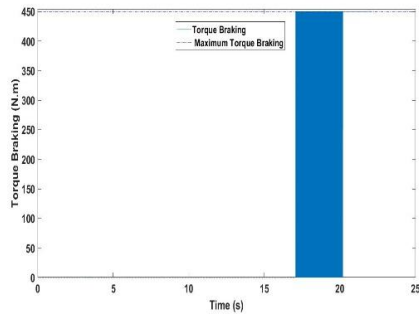

Figure 3 (b) Effect of APF during Braking

Figure 3 (c) Relationship between Torque Braking and Time
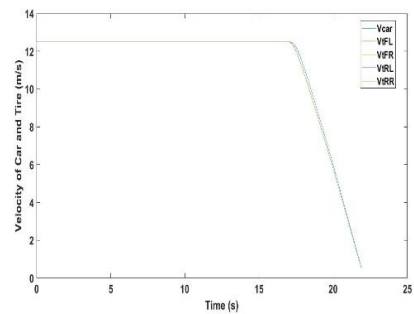

Figure 3 (d) Relationship of Velocity of the Vehicle with Velocity of each Tire
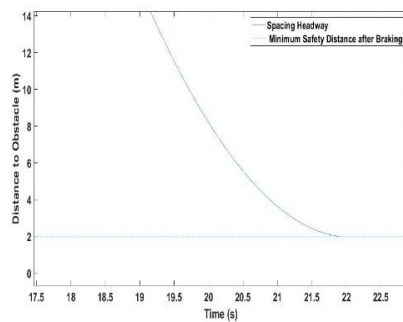

Figure 3 (e) Minimum of Safety Distance from Obstacle
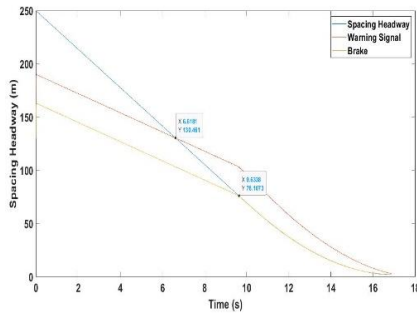
Velocity of the vehicle = 65 km/h

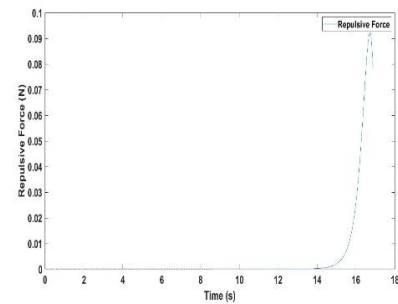**Figure 4 (a)** Point of activation an AEB system

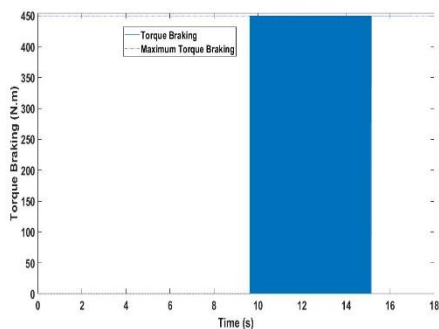**Figure 4 (b)** Effect of APF during Braking

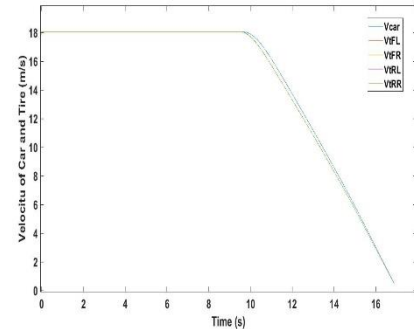**Figure 4 (c)** Relationship between Torque Braking and Time

Figure 4 (d) Relationship of Velocity of Vehicle with Velocity of each Tire
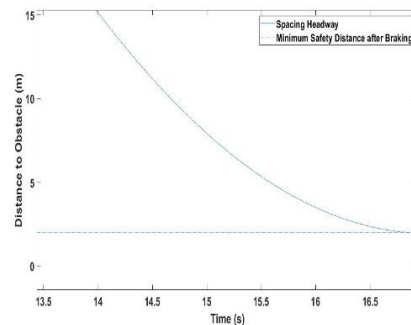
Figure 4 (e) Minimum of Safety Distance from Obstacle

5. CONCLUSIONS

In conclusion, as the development to the common Autonomous Emergency Braking system, the authors introduce an assimilation of AEB system with the Potential Field Risk threat strategy to avoid the close-miss incidents. APF profitably calculate the threat of the frontal static obstacle. Based on the threat measurement, the host vehicle successfully activates the desired braking actuations to grant it for a full vehicle stopping. The inclusion of PF into the AEB grant the vehicle to manage the safe distance of 2.0 m from the obstacle. For future works, more complicated scenarios and higher speed of the vehicle will be simulate for the improvement of the system. Varied driving style arrangement in the emergency braking scheme by varies drivers shall be investigated to strengthen the AEB achievement. This research hopefully will enhance the system of an AEB for the future work.

ACKNOWLEDGEMENT

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