DESIGN AND MANUFACTURING OF AN ACTIVE BRAKE SYSTEM MODEL USING LIDAR SENSOR

THIẾT KẾ VÀ CHẾ TẠO MÔ HÌNH HỆ THỐNG PHANH CHỦ ĐỘNG SỬ DỤNG CẢM BIẾN LIDAR

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ABSTRACT

The research article investigates the operating principles of the Automatic Emergency Braking (AEB) system, designs a 3D model, and manufactures a simulated model of the brake system's operation. The model operates with various warning levels. The device is designed with four warning levels, each displayed and acted upon to alert the driver of danger. In cases where the driver does not engage the brake pedal, the system will automatically activate the automatic braking mechanism. Experimental research is conducted at various speed ranges and distances, demonstrating that the model operates stably and aligns with the working principles of the actual system.

Keywords: *Automatic emergency braking; educational model; automatic emergency braking system.*

TÓM TẮT

Bài báo nghiên cứu nguyên lý hoạt động của hệ thống phanh khẩn cấp tự động AEB, thiết kế mô hình 3D và chế tạo mô hình mô phỏng hoạt động của hệ thống phanh. Mô hình hoạt động với các mức cảnh báo khác nhau. Thiết bị được thiết kế với bốn cấp độ cảnh báo, các cấp độ cảnh báo lần lượt được hiển thị và tác động để người lái nhận biết nguy hiểm. Trong trường hợp người lái không tác động lên bàn đạp phanh, hệ thống sẽ tự động kích hoạt cơ cấu phanh tự động. Nghiên cứu thực nghiệm được thực hiện với nhiều dải tốc độ, cự ly khác nhau cho thấy mô hình hoạt động ổn định và phù hợp với nguyên lý làm việc của hệ thống thực tế.

Từ khóa: *Phanh tự động khẩn cấp; mô hình giáo dục; hệ thống phanh tự động khẩn cấp.*

1. INTRODUCTION

Rear-end collisions occur in various ways similar to other types of collisions. They are often the result of unsafe driving behaviors such as speeding, inattention, distracted driving, fatigue, and driving under the influence of alcohol or drugs. They can also easily stem from mechanical failures of the vehicle, such as faulty brakes or poor vehicle maintenance, like flat tires or malfunctioning taillights. According to NHTSA in the year 2020 in the United States, the total number of accidents related to rear-end collisions was 1,014,408, with 1,243 fatalities, accounting for 6% of the total accidents from rear-end collisions. The number of injured people was 308,282, accounting for 20.4%, and property damage-related losses were 704,820, accounting for 21.9%. In most cases, individuals consider the driver at the rear end to be at fault in accidents involving pedestrians and vehicle operators [1].

The group of authors, including Muhammad Faiz Hilmi and colleagues, approached the subject by calculating the braking time of the AEB system by examining the maximum deceleration speed in a severe accident scenario on urban roads in Penang to optimize the system to suit local traffic conditions [2]. Author Ritesh Kapse from India studied the topic 'Implementing an Autonomous Emergency Braking with Simulink using two Radar Sensors,' by implementing emergency autonomous braking using two radar sensors with different coverage angles [3].

In China, Wei Yang and team researched the active collision avoidance capability in the longitudinal direction of the Automatic Emergency Braking system for pedestrians (AEB-P). By studying related theoretical systems such as Time-to-Collision (TTC) and safe braking distance, an AEB-P warning model was established. CarSim and Simulink simulation models of the AEB-P system were set up and analyzed, conducting multi-condition simulation analysis. The results showed that the proposed control strategy is reliable and can flexibly allocate early warning time and braking according to actual working conditions, reducing pedestrian collision incidents. CarSim and Simulink simulation models of the AEB-P system were set up and analyzed, conducting multi-condition simulation analysis. The results showed that the proposed control strategy is reliable and can flexibly allocate early warning time and braking according to actual working conditions, reducing pedestrian collision incidents [4].

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2. THEORETICAL BASIS

The real-time time-distance is the distance between a moving vehicle and a pedestrian, and also the distance between two moving vehicles. The time needed for the back-and-forth movement of the ultrasonic wave after hitting an obstacle is called time signal (t_{tp}). The real-time time-distance d obtained from the ultrasonic sensor is calculated using the formula:

$$d = \frac{t_{tp}}{2}.v_{at} \quad (1)$$

When considering the pedestrian's walking speed as negligible compared to that of car A (assuming it to be zero), the braking distance between car A and the pedestrian is:

$$d_{c1} = V_A\left(t_r + \frac{t_i}{2}\right) + \frac{V_A^2}{2\mu g} + d_{min} \quad (2)$$

This method is used for non-moving obstacles or pedestrians whose speed is assumed to be 0. The microcontroller used the car's speed (V_A) to determine how to brake to the limit (d_{c1}) is compared with the real-time time-distance (d) between the vehicle and the non-moving obstacle.

The safe braking distance between two moving vehicles (Vehicle A and Vehicle B) can be calculated using the safe braking distance model as follows:

$$d_{c2} = V_A t_r + \frac{(V_A - V_B)t_i}{2} + \frac{V_A^2 - V_B^2}{2\mu g} + d_{min} \quad (3)$$

Where: d_{c1}, d_{c2} - Braking distance to decelerate, V_A - Speed of Vehicle A, V_B - Speed of Vehicle B, μ - Coefficient of friction of the road, t_r - otal reaction time of the driver and the time to coordinate braking, typically ranging from 0.8 seconds to 1.2 seconds, t_i - Braking time interval during deceleration, typically varying from 0.1 seconds to 0.2 seconds, g - Acceleration due to gravity (9.81m/s^2) and d_{min} - Minimum distance between the vehicle and the obstacle when stopping, ranging from 1m to 4m.

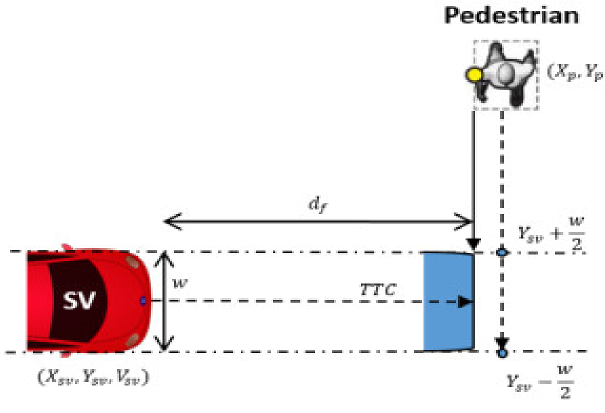

Figure 1. Collision computation diagram

If the real-time time-distance d_{c1} and d_{c2} greater than d, so it is a safe state, and the vehicle can continue at its current speed. If not, d_{c1} and d_{c2} less than or equal to d, If the driver does not decelerate or take other safety measures, this state is assessed as dangerous, and automatic speed reduction on car A will be initiated immediately by the controller to avoid a collision with car B.

In the scenario between a subject vehicle and a pedestrian as depicted in the diagram, a simple index to calculate the risk of collision is the Time-To-Collision (TTC). TTC is calculated based on the temporary distance between the vehicle and the pedestrian d_f along with the velocity of the vehicle v_{sv}, and is expressed as follows:

$$TTC = \frac{d_f}{v_{sv}} \quad (4)$$

In an intelligent braking system that predicts collisions and initiates emergency braking based on TTC, the braking distance of the vehicle is a crucial factor directly related to the system's performance. A shorter braking distance provides more time to avoid a collision. Additionally, the accuracy of collision prediction is enhanced as it can be verified multiple times. The theoretical braking distance is represented by:

$$d_{stop} = -\frac{v_{sv}^2}{2a_{aeb}} \quad (5)$$

Where: a_{aeb} is the deceleration of the intelligent system, and d_{stop} represents the braking distance when decelerating in a_{aeb}.

In this scenario, considering two cars moving on the same lane and an imminent collision, in reality, both vehicles are constantly in motion. Therefore, the TTC calculation is based on the velocities of both the front and rear vehicles:

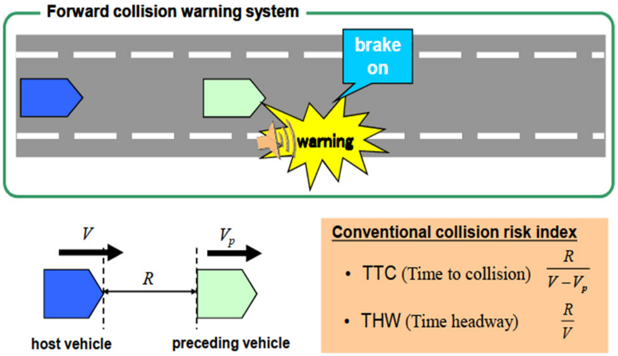

Figure 2. The computational model of two cars colliding with each other

The calculation formula is:

$$TTC = \frac{R}{V - V_p} \quad (6)$$

In which: R is the distance between the two vehicles; V is the velocity of the subject vehicle; V_P is the velocity of the vehicle in front.

The distance and velocities of the two vehicles are continuously sensed, measured, and transmitted to the central processing unit for analysis and subsequent actions, as illustrated in the above scenario.

When the driver starts the vehicle, the sensors are in obstacle detection mode. Two sensors will detect if there are no obstacles, and they will continue scanning until one of the sensors detects an obstacle. If an obstacle is detected, the ultrasonic sensor will measure the distance to the obstacle. The signal from the front sensor is sent, and the controller will check if the obstacle is within a safe distance to apply maximum braking force to stop the vehicle. Conversely, the controller will provide a warning signal to the driver based on the severity if the obstacle is not within a safe distance. This sequence continues as long as the sensors detect obstacles.

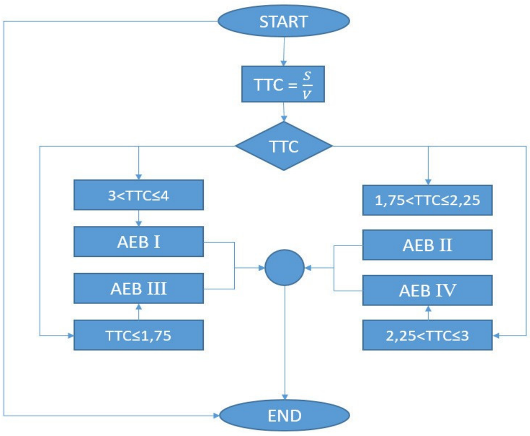

Figure 3. Algorithm flowchart

If there are any obstacles on the road, the object's information data will be continuously sent to the central control unit. Simultaneously, combined with the wheel speed data, the system will calculate the likelihood of a collision and issue a warning level based on the TTC parameter.

$$\mathrm{TTC} = \frac{\mathrm{S}}{\mathrm{v}} \qquad (7)$$

Where: S - Distance to the object; v - Wheel speed.

TTC stands for Time To Collision, an indicator assessing the likelihood of a collision between an object and a moving vehicle. The smaller the TTC value, the higher the probability of a collision, and vice versa. Therefore, the system needs to differentiate dangerous situations into specific cases to provide appropriate warnings and interventions [4, 5].

For the experimental model serving students for study and research, practical experiments with a long distance are not feasible due to classroom limitations, nor is it possible to have the model move at a high speed due to safety considerations. Therefore, after consulting various studies [7-9], the authors established a suitable TTC threshold with a distance of 12m and speeds that the model could initiate.

When 4s ≤ TTC < 3s, the AEB system will switch to a warning state by flashing lights to remind the driver to brake and reduce speed. This is the first warning level.

When 3s ≤ TTC < 2.25s, if the driver has not applied the brake in time, the AEB system shifts to braking level I, corresponding to the second warning level.

When 2.25s ≤ TTC < 1.75s, the AEB system shifts to braking level II, corresponding to the third warning level.

When TTC ≤ 1.75s, the AEB system shifts to braking level III. The system will maintain this state until the wheels come to a complete stop or the TTC value increases, shifting to another braking state

The actual model of the smart brake system is shown in Figure 4.

Figure 4. System model after completion

Table 1. TFmini-S IIC LiDAR 12m distance sensor parameters

Name	TFmini-S IIC LiDAR 12m
Signal out	Analog
Frequency	60Hz
Measuring distance	0 , 1 ~ 12m
Resolution	1cm
Voltage	5V
Scanning angle	2°
Communicate	UART, IIC, IO
Operating temperature	-10°C ~ 60°C

Working principle of the system model: The model operates at 4 different warning levels, signals about the distance and relative speed of the vehicle's movement are transmitted to the central processor. Based on warning time calculation, TTC will issue warnings including: level 1 - light; level 2 - sounds and lights; level 3 - sounds, lights and belts; Level 4 - the highest level, the system impacts the brake system to emergency stop the vehicle. From warning levels 2 to 4, if the driver does not act on the brake system, the brake pressure will automatically be provided with the corresponding ratios: 25%; 50%; 75%; 100% for the purpose of stopping the vehicle or minimizing collision damage (if any).

3. RESULTS AND ANALYSIS

3.1. Experimental results

For the first test scenario, the authors aim to assess the collision prevention capability of the system in certain emergency situations such as:

- The driver being distracted and not detecting a moving vehicle in front with no signs of slowing down.
- The vehicle in front decelerating, but the driver not recognizing it and failing to slow down.

The results of the first test at a speed of 10 km/h are shown in the following Table 2.

Table 2. Test results at a speed of 10km/h

Distance (m)	V (km/h)	TTC(s)	Warning level
10	10	4.2	0
9	9	3.2	1
7.3	7.2	2.6	2
6.4	5.3	1.9	3
4.2	4	1.4	4
2.9	0	∞	Safe

The second experiment with an initial speed of 7km/h was conducted in a similar manner to the first one:

Table 3. Test results at a speed of 7km/h

Distance (m)	V (km/h)	TTC(s)	z	Warning level
8	7.7	4.6		0
6.6	6.4	2.7		1
5.4	5.1	2.2		2
4.0	4.5	1.9		3
3.2	2.9	1.4		4
2.3	0	∞		Safe

In both cases, a safe state was achieved as the speed reduced to 0km/h before the In both cases, a safe state was achieved as the speed reduced to 0km/h before the collision. The remaining distance between the two cars after stopping was 2.9m and 2.3m respectively for the scenarios with speeds of 10km/h and 7km/h.

For the second test, the authors aimed to evaluate the collision prevention ability of the system in certain emergency situations such as:

- The driver unexpectedly accelerates while passing through an intersection with a red light.
- The driver mistakenly confuses the accelerator and brake pedals in unforeseen circumstances that could lead to a collision.

The first experiment with a speed of 7km/h and a distance of 10m to the front vehicle was conducted:

Table 4. The second experiment with a speed of 7km/h

Distance (m)	V (km/h)	TTC(s)	Warning level
3,5	30	0,42	0
2,9	33	0,35	1
2,4	37	0,29	2
1,8	41	0,23	3
0,9	20	0,12	4
0,6	11	0,15	4
0,4	0	∞	Safe

The second experiment with a speed of 10km/h and a distance of 12m to the front vehicle was conducted similarly:

Table 5. The results of the second experiment with a speed of 10km/h

Distance (m)	V (km/h)	TTC(s)	Warning level
12	10	4.3	0
11.2	10.3	3,5	1
8.2	15.2	2.2	2
7.1	19.8	1.3	3
5.2	22.5	0.8	4
4.3	5	1.3	4
3.7	0	∞	Safe

In both cases, a safe state was achieved as the speed reduced to 0km/h before the collision. The remaining distance between the two cars after stopping was 3.3m and 3.7m with speeds of 7km/h and 10km/h.

The final test assesses the collision prevention capability of the car with pedestrians or bicycles unexpectedly crossing, a very common scenario in traffic.

Table 6. Results of the third test at a speed of 10km/h

Distance (m)	TTC (s)	Warning level
2	1	4
4	1.6	3
6	2.2	2
8	2.9	2
10	3,6	1
12	4,4	Safe

For the same speed, the farther the distance, the longer it takes for the speed to decrease because the warning level is lower. The closer the distance, the faster the car stops.

The experimental results demonstrate that the model operates reliably across various speed ranges, in diverse scenarios, and the different levels of collision prevention warnings are consistent with the operational principles of the constructed model.

4. CONCLUSION

The study successfully constructed and experimentally validated test scenarios for an automatic emergency braking system model. However, due to constraints in time, investment, equipment, purpose of use, operational space, the design model presented by the authors aimed to illustrate the principles and investigate various operational cases of the automatic emergency braking system when detecting obstacles and potential collisions.

The constructed model serves the purpose of research and learning, enabling students to easily practice, experiment, and understand the principles of the automatic emergency braking system. The model is highly applicable, enabling assessment and investigation of many scenarios under classroom conditions.

Due to space limitations, assumptions were made to suit the context. The results did not describe the actual motion of the car with real distances between the two vehicles. Nevertheless, the model elucidated the working principle of the AEB system, allowing students to engage with technology. The simulated cases demonstrated calculated results and continuous updates with sensors and code segments. Different speeds resulted in different safe distances. This serves as a foundation for researching and developing upgraded models with high applicability

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THÔNG TIN TÁC GIẢ

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