

Warning Device for Right Turning Safety of Freight Cars in Port Area

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Abstract

In order to reduce the traffic accident rate related to the right turn of vehicles on port roads, this paper summarizes and analyzes the movement track of freight cars when turning right, using clothoid to describe the trajectory of right turn curvature gradient to expound the formation mechanism of inner wheel difference of freight cars in right turning. Based on the practical application of right turning dangerous area, a safety warning device for vehicle right turning is designed.

Keywords

Port Area; Clothoid; Inner Wheel Difference; Right Turning Dangerous Area; Warning Device.

1. Introduction

According to Ackermann's steering geometry principle, when the vehicle turns right, all wheels take the same point as the steering center, and the steering radius is different. There is a radius difference between the front inner wheels and rear inner wheels when steering. Namely, it is the inner wheel difference. Because of its unique body structure, the inner wheel difference of container semi-trailer truck is larger than that of ordinary truck when turning, which has buried more hidden dangers of accidents and produced more serious security threats. Chu et al. [1] analyzed the causes and sizes of three types of freight cars' right turn inner wheel difference, and further analyzed the important influencing factors of freight cars' right turn inner wheel difference to established the mathematical model; Based on the real vehicle experiment, Wang et al. [2] fitted the right turning trajectory of the vehicle, verified the formation process of the inner wheel difference, constructed the relationship model between the visible length of the right rear-view mirror and the turning angle in the process of right turning, and discussed the effective mechanism of the right turning rear-view mirror of the semi-trailer; Zhang et al. [3] discussed the spatial distribution and inner wheel difference effect of A-pillar blind area and rear-view mirror blind area in the process of commercial vehicles turning right, constructed the characteristic index reflecting the time-space relationship between commercial vehicles and pedestrians, and proposed an anti-collision warning method for commercial vehicles blind area based on trajectory prediction and fuzzy pattern recognition; Wang [4] put forward the calculation method of blind area of right turn sight of freight cars and the safety evaluation index of Road intersection, and established the right turn model of freight cars by using MATLAB software; Zhou et al. [5] took the dump truck as an example to study the size of the inner wheel difference at different corners, and designed a warning device on the side of the car body to illuminate the dangerous area formed by the inner wheel difference when the car turns; Based on the measured traffic data and according to the road occupancy rate, Zhou et al. [6] divided the vehicles into four types, analyzed the characteristics of the front sight distance, and proposed the calculation model of vehicle conversion coefficient to calculate the theoretical capacity value of the merging area. In this paper, based on the practical application of the right turn dangerous area and the analysis of the inner wheel difference of

the right turn, a warning device for right turning safety is designed for freight cars on the port road.

2. Calculation of vehicle right turning trajectory and inner wheel difference

2.1. Analysis of road traffic characteristics in port area

The port road is the skeleton of the port layout and the artery of logistics transportation, which plays the role of the passage of goods circulation and information exchange. Different from the general urban roads and expressways, the port road is determined by the port logistics technology, and the vehicle composition is complex: the composition includes passenger cars, ordinary trucks, container trucks, semi hung trucks, oil tanks, etc. The traffic in the port area has the characteristics of high rate of big cars, among which container trucks and large and medium-sized trucks account for 30% to 80% of the traffic flow. The common characteristics of large and medium-sized freight cars such as container trucks are large body volume, large vehicle weight, fast driving speed, large inertia of vehicles, and blind area of vision. The emergency response capacity is weak, which can easily lead to serious traffic accidents.

2.2. Right turn trajectory of road vehicles in port area

Due to the wide road width, large linear size of intersections and long passing time of slow traffic, safety island is usually set up to organize the second crossing; At the same time, the speed of motor vehicles is high, and there is a traffic conflict between right turning motor vehicles and slow traffic, which constitutes a potential safety hazard. This paper analyzes the right turn behavior and track of road vehicles in port area.

The right turn control scheme of the Port Road intersection is the same as that of the general urban road intersection, which usually does not set the right turn signal control, and can pass in any phase. It is assumed that there is no slope change at the intersection. According to the general driving behavior, the right turn assumption of motor vehicle drivers at the road intersection in the port area is as follows:

- a. Keep straight into the intersection;
- b. Turn the steering wheel evenly to turn the vehicle to the right;
- c. Keep a certain steering angle;
- d. Turn the steering wheel evenly to make the direction return to the right direction;
- e. Keep straight into the target lane.

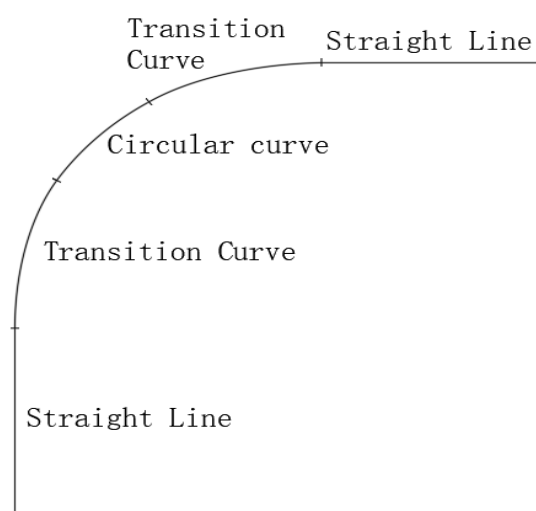


Figure 1. Schematic diagram of vehicle right turn trajectory

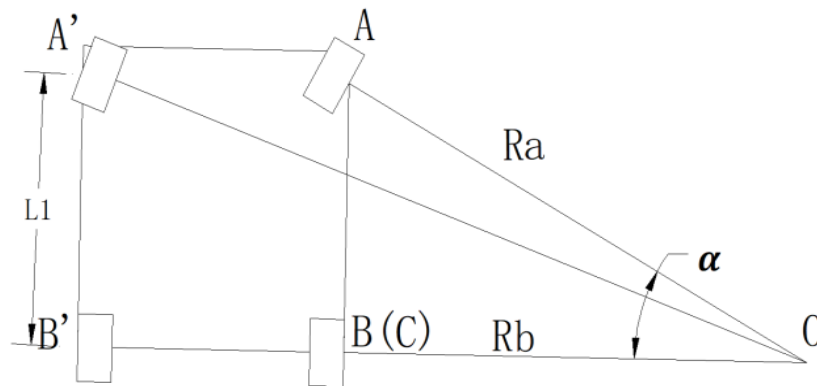


Figure 2. Right turning radius diagram of ordinary freight cars

In step 2, it is assumed that the steering angle of the right front wheel of the vehicle increases uniformly from zero radian to α radian in period t_1 . At the last moment of t_1 , as shown in the figure above, the turning radius R_a of the right front wheel a of an ordinary freight car can be calculated by formula (1):

$$R_a = L_1 \times \csc(\alpha) \quad (1)$$

L_1 is the front and rear wheelbase of the vehicle. The turning radius R_b of the right rear wheel B is calculated by equation (2):

$$R_b = L_1 \times \cot(\alpha) \quad (2)$$

In t_1 period, the radius of curvature of the right front wheel of the vehicle turns right from infinity to R_a evenly, and the track of the right front wheel is an arc with gradual curvature. The length of the arc L_{s1} can be obtained by using the integral idea, as shown in equation (3):

$$L_{s1} = \frac{\alpha L_1}{t_1^2} \int_0^{t_1} t^2 \csc\left(\frac{\alpha t^2}{t_1^2}\right) dt \quad (3)$$

t is any time in t_1 period. The length of the track of the right rear wheel B of the vehicle is calculated by formula (4):

$$L_{s1} = \frac{\alpha L_1}{t_1^2} \int_0^{t_1} t^2 \cot\left(\frac{\alpha t^2}{t_1^2}\right) dt \quad (4)$$

In road design, easement curve is set to help vehicles transition from straight line to circular curve. Generally, spiral equation is used in easement curve. Based on this idea, this paper uses the roundabout to describe the trajectory of the right turn at the level intersection. The trajectory equation of gyrate is

$$rl = A^2 = (\sqrt{RL_s})^2 \quad (5)$$

r is the radius of curvature of a point on the cyclotron (m); L is the curve length from a point to the origin of the cyclotron (m); A is the cyclotron parameter; R is the radius of the circle curve connected by the cyclotron (m); L_s is the length of spiral curve of cyclotron (m). The parameters of the gyrotron line of the right front wheel a of the ordinary freight car can be calculated by substituting the (1) and (3) into the (5) formula, as shown in formula (6):

$$L_{s1} = \frac{\alpha L_1^2 \csc(\alpha)}{t_1^2} \int_0^{t_1} t^2 \csc\left(\frac{\alpha t^2}{t_1^2}\right) dt \quad (6)$$

Similarly, the curve parameters of right rear wheel B of ordinary freight car are shown in equation (7):

$$L_{s1} = \frac{\alpha L_1^2 \cot(\alpha)}{t_1^2} \int_0^{t_1} t^2 \cot\left(\frac{\alpha t^2}{t_1^2}\right) dt \quad (7)$$

In step 4, it is assumed that the steering angle of the right front wheel of the vehicle changes uniformly from α Reduce to zero radians. The calculation method of arc length and gyrate parameters of this curvature transition section is the same as (1) ~ (7).

2.3. Calculation of inner wheel difference of vehicle turning right

Slow traffic is usually released in the same phase with the same direction of straight ahead vehicles. In this phase, the right turning vehicle and the straight slow traffic will cause traffic conflict points. Some of the drivers' aggressive driving behavior, the irregular operation of novice drivers and the visual blind area of large trucks have buried hidden dangers. According to Ackerman steering geometry, all wheels point to the same center of the rear wheel axis when the vehicle is turning, and the angle of the inner steering wheel is greater than the outer steering wheel angle. Therefore, the steering radius length of different wheels is different. In the same side wheel, the steering radius of the front wheel is larger than the rear wheel steering radius. In the process of vehicle steering, there are time difference and position difference between front and rear wheels reaching the same section with certain width. The cross-section position of front wheel arrival is far away from the center of steering circle compared with that of rear wheel. The two spatiotemporal separated driving tracks constitute the inner wheel difference, forming a dangerous area of crescent shape. If we don't understand this mechanism, it may lead to the negligence of the driver and the slow traffic, and lead to the occurrence of accidents.

In step 3 above, it is assumed that the vehicle keeps a certain steering angle, and each wheel generates a group of circular arc tracks with the same center and different radii. Inner wheel difference of front and rear wheels inside right turn of ordinary freight car ΔR_1 , namely, the calculation method of turning radius difference is shown in the following equation (8):

$$\Delta R_1 = R_a - R_b = L_1 \csc(\alpha) - L_1 \cot(\alpha) = \frac{L_1(1-\cos(\alpha))}{\sin(\alpha)} \quad (8)$$

R_a and R_b are respectively the turning radii of the front and rear wheels inside the vehicle, which are calculated by equations (1) and (2). Container trucks account for a large proportion of road traffic vehicles in the port area. The vehicle type is usually semi trailer truck, which is composed of tractor head and trailer carriage. Based on the analysis of the right turn inner wheel difference of common freight cars, the right turn inner wheel difference of semi trailer freight cars is described and analyzed.

The trailer car of semi-trailer truck is only equipped with wheels at the rear of the car, and the front part is connected with the tractor head by the traction pin device. There is a certain degree of freedom between the tractor head and the semi-trailer car, so there is an angle between the tractor head and the car during driving β . This makes the calculation of the inner wheel difference of the semi-trailer truck no longer applicable to equation (8). Referring to the existing research[2], a virtual axle is introduced into the front of the trailer. As shown in the figure below, the virtual axle is C-C' axis, and wheel C coincides with the rear wheel B of the tractor. The two motion states are the same, that is, the steering angle, driving speed, acceleration, etc. are completely equal. For the trailer car, when following the steering motion of the tractor head, the turning radius of the virtual wheels C, C' and the real wheels D, D' at the rear intersects at a point O' on the C-C' axis, and the steering angle of the right front wheel C is β . In the process of turning right at the intersection of roads in the port area, the semi-trailer truck also meets the assumption of the above five steps, and the motion trajectory of the semi-trailer truck is essentially the same as that of the ordinary truck, and the number of semi-trailer trucks is different. The trajectories of wheel A and wheel B form the first dangerous area of crescent shape, and the trajectories of wheel C and wheel D form the second dangerous area of crescent shape. Design of semi trailer truck ΔR_2 inner wheel difference is the sum of the above two groups of radius differences, and the calculation method is shown in formula (9):

$$\Delta R_2 = (R_a - R_b) + (R_c - R_d) = \frac{L_1(1-\cos(\alpha))}{\sin(\alpha)} + \frac{L_2(1-\cos(\beta))}{\sin(\beta)} \quad (9)$$

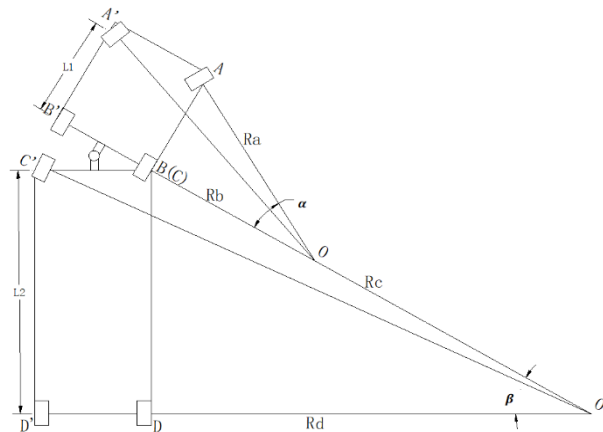


Figure 3. The inner wheel difference of the semi-trailer turning right

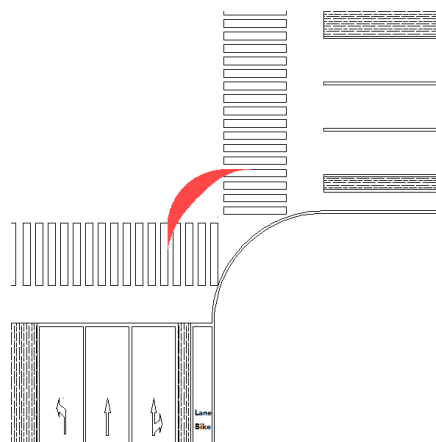


Figure 4. Right turn danger area diagram

3. Warning device for right turning safety

3.1. Device principle

The right turn safety warning device is based on the practical application of the right turn dangerous area. According to the characteristics of the large proportion and large number of large trucks on the road in the port area, and the existence of objective visual blind area in the process of right turn, a vehicle right turn safety warning device is designed. The basic strategies are as follows:

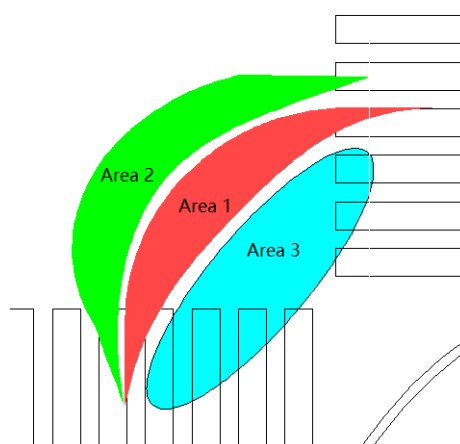


Figure 5. Schematic diagram of detection area

a. In the right turn dangerous area (area 1) and outside the dangerous area marking, sensors are embedded on the ground to detect whether there are vehicles passing by and driving direction. The outside of the dangerous area marking near the intersection center (far away from the roadside) is area 2, and the direction far away from the intersection center (near the roadside) is area 3; Right turning vehicles must pass through area 2 before entering area 1; The warning signal lasts for a certain period of time after it is sent out, covering the driving time of any vehicle turning right through the crescent shaped dangerous area.

b. If only area 2 detects the vehicle passing by and the driving direction is right turn, activate the light-emitting device and roadside voice device in the right turn danger area to send out the normal warning message.

c. If a vehicle is detected in area 2 and the direction of driving is right turning, and a vehicle or pedestrian is detected in area 1, the light-emitting device and voice device will send out a strong warning message.

d. If the area 2 detects that the vehicle is passing and the driving direction is turning right, and the area 3 detects that the vehicle or pedestrian is passing and the moving direction is straight, the light-emitting device and the voice device send out a strong warning message.

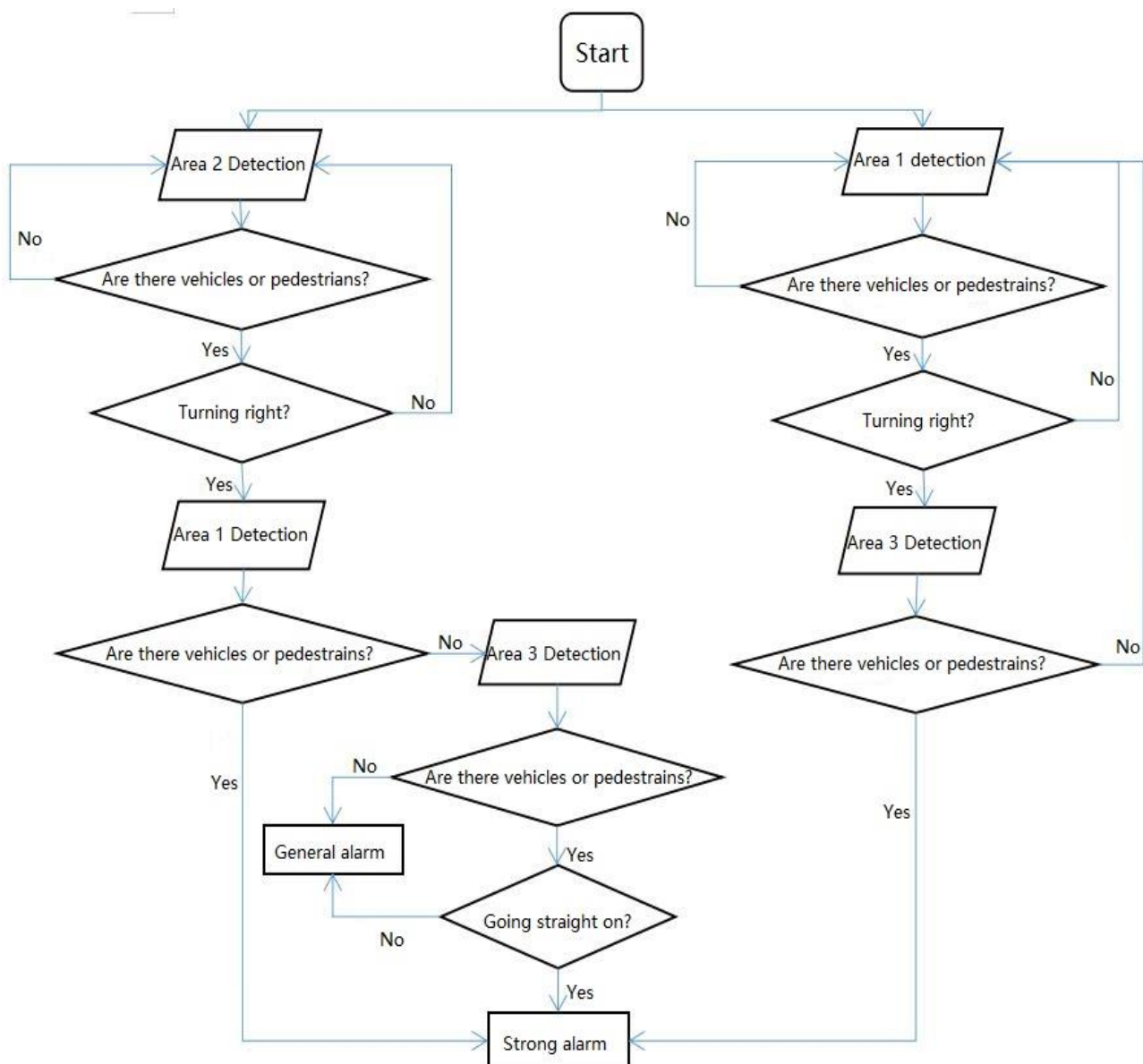


Figure 6. Warning strategy for right turning safety of freight cars in port area

e. If a vehicle is detected passing by in area one and the direction of driving is right turning, and a vehicle or pedestrian is detected in area three, the light-emitting device and voice device will send out a strong warning message.

The right turn safety warning device can detect the right turn dangerous area and its surrounding traffic conditions, judge whether it is motor vehicle or slow traffic by the driving direction of traffic participants, evaluate the risk level according to the combination of different traffic conditions, and warn slow traffic people to avoid danger by optical and sound methods.

3.2. Device model

In this paper, the vehicle right turn safety warning device is proposed, which is composed of sensors, single-chip microcomputer, sound raising device, light-emitting device and other important parts. In the future, the STC89C52 MCU experimental board will be used to simulate the function of the device, Keil uVision software will be used to compile the program with C language, and stc-isp software will be used to download the program into the MCU.

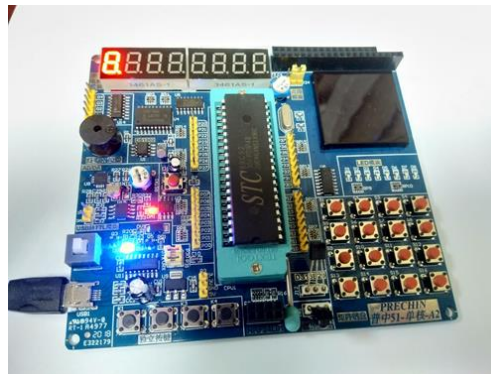


Figure 6. MCU experimental board

4. Conclusion

Based on reasonable simplification and assumption, the right turn behavior of road vehicles in port area is summarized into five steps, and the arc length calculation formula of angle transition section is obtained by using integral idea; According to the idea of transition curve in road survey and design, the trajectory of turning angle transition section in right turning trajectory is described by gyrate. Based on the principle of inner wheel difference and the practical application of right turn dangerous area, a right turn safety warning device for port road is designed, and its function and warning strategy are described in detail. The device adds detection and real-time feedback function on the warning function of right turn dangerous area, further excavates the use value of right turn dangerous area, enhances its warning function, and has good practical application value; The expected cost of the device meets the requirements of economic feasibility for popularization and application, and the application prospect is good. In the future, MCU model with the same function will be made.

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