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A Method for Performing Vehicle Driving Safety Evaluation by Using Satellite Positioning Data

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Abstract. At present, the satellite positioning data of vehicles is mainly used to monitor the parameters such as position and speed. From the perspective of vehicle coordination, there is a lack of real-time evaluation of driving safety in combination with driving conditions. This paper proposes a method for vehicle driving safety evaluation using satellite positioning data. It proposes to use the satellite positioning data to explore deeper information such as road alignment without relying on other extended information. The acceleration interference value is introduced as an important index for vehicle driving safety evaluation. Combined with the result of this indicator, the unsafe risk points in the driving process are counted to realize the dynamic evaluation of the vehicle driving process safety. Combined with the actual vehicle test data collected at the vehicle test site, the recognition results given by the method are compared and analyzed by referring to the relevant national standards. Test and comparison results show that the method can achieve the expected results. This will help road transport companies and users to detect and prevent vehicle driving safety risks in a timely manner.

Keywords: acceleration interference value, road alignment, satellite positioning data, vehicle driving safety

1 Preface

During the driving process, we should consider the driver, road conditions, natural environment, vehicle driving status and other factors, and then evaluate the current driving safety of the vehicle in real time. At present, there are few studies to evaluate the driving safety of vehicles from the perspective of various elements of the traffic system. The real-time safety evaluation during the driving process of the vehicle can timely discover the driver's unsafe driving operation, and thus carry out preventive intervention and management, which has a direct effect and great significance on reducing the occurrence of traffic accidents. At present, many scholars are devoted to the research of vehicle speed warning system [1-2], in order to improve the active safety of vehicles. However, the existing and easily acquired satellite positioning data of the vehicle is less used to carry out the safety evaluation of the combination of the vehicle and the road.

The birth of satellite positioning systems (such as GPS/Beidou system, etc.) has brought great changes to our daily life. With this technology, detailed satellite positioning data of vehicles can be obtained, which can fully reflect the real-time running status of vehicles. At present, the satellite positioning system has been widely used in various types of road transportation enterprises, including individual users. How to make full use of these massive satellite positioning data to calculate and obtain accurate vehicle driving safety evaluation indicators, and carry out safety evaluation of the operation process, also

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has important value and practical significance. In the past application research, satellite positioning data is mainly used to monitor the position and speed of the vehicle. The data is not combined with the road line shape to analyze the relationship between the current position of the vehicle and the highway parameters.

Therefore, based on the existing theoretical methods for the analysis of the impact of road alignment on driving safety, this paper is based on the study of a method that relies solely on the field of the satellite positioning data itself, and explores the deep-level information such as the road line type. The purpose of the method is to accurately analyze the running state of the positioned vehicle and the basic driving environment information, calculate and count the unsafe risk points during the driving process, and dynamically evaluate the safety of the driving of the vehicle in real time, and does not depend on other extended information such as external access to geographic information [3-5].

This paper introduces the acceleration interference value as the specific evaluation parameter index, and uses the satellite positioning data to dynamically calculate this index to evaluate the driving safety of the vehicle. This indicator can well describe the influence of road line type and vehicle speed on the safe driving state of the vehicle, so that the dynamic evaluation of vehicle driving safety is more comprehensive, and it can reflect and judge whether the vehicle is in a safe state during driving [6-7].

This paper is divided into four chapters. The preface introduces the background of the proposed method and the problems to be solved. Section 1 gives the specific method for calculating the acceleration interference value using satellite positioning data. Chapter 2 combines the relevant national standards and uses the specific vehicle operating data to test and verify the method. Finally, the research work was summarized in the conclusion section.

2 Technical Solution

This paper proposes a method for vehicle driving safety evaluation using satellite positioning data. Using satellite positioning data records stored in the monitoring center system database or satellite positioning vehicle terminal, first select the specific vehicle to be evaluated, according to the statistical time period, screen out the all satellite positioning data records for the vehicle. Establish the acceleration arc model by identifying the circular arc segment algorithm, judge the threshold value of the vehicle driving safety, calculate and count the unsafe risk points during the driving process.

2.1 Calculation of Acceleration Disturbance Model Based on Road Plane Curve

The road condition, slope and turning radius and speed of the road surface will affect the driving of the vehicle. Therefore, the concept of acceleration interference has been proposed. In 1962, Jones and Potts proposed mathematical equations for acceleration disturbances, see equation (1).

$$\sigma = \sqrt{\frac{1}{T}\int_0^T [\alpha(t_i) - \overline{\alpha}]^2 - dt} \qquad \textbf{(1)}$$

In the equation: σ is the acceleration interference value; T is the total time of vehicle operation; $\alpha(t_i)$ is the acceleration at time i; $\overline{\alpha}$ is the average acceleration. This type is only used when the vehicle is moving (ie, the speed is significantly greater than 0).

Taking the acceleration interference on the horizontal plane as an example, a two-dimensional acceleration interference model can be obtained:

$$\sigma = \left\{ \frac{1}{T}\int_0^T [\frac{|\dot{M}_x \ddot{M}_x^2| + |\dot{M}_y \ddot{M}_y|}{\sqrt{\dot{M}_x^2 \dot{M}_y^2}} - \frac{1}{T}\int_0^T [\frac{|\dot{M}_x \ddot{M}_x| + |\dot{M}_y \ddot{M}_y|}{\sqrt{\dot{M}_x^2 \dot{M}_y^2}} dt]^2 \, dt \right\}^{\frac{1}{2}} \qquad \textbf{(2)}$$

Where: $\dot{M}_x$, $\dot{M}_y$ and $\ddot{M}_x$, $\ddot{M}_y$ are the first-order and second-order partial derivatives of the trajectory function M for x, y, respectively, ie the velocity and acceleration in the x, y direction.

In the road design stage, the road plane curves are all connected by multiple arcs, so we can think of a curve as a multi-segment arc, as shown in Fig. 1, and Fig. 2 is a parameter diagram of the road plane curve.

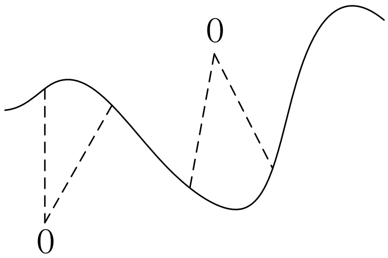

Fig. 1. Road plane curve

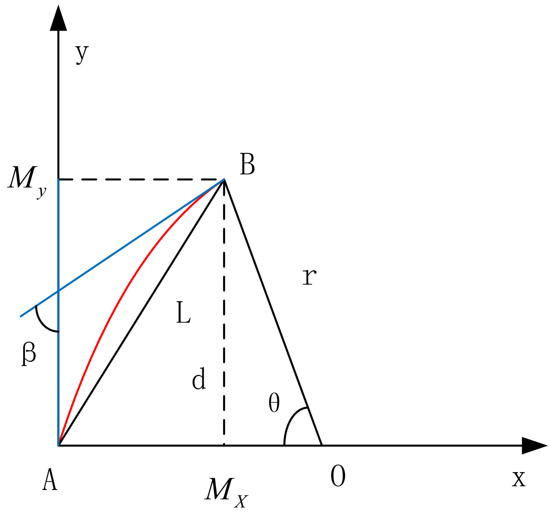

Fig. 2. relationship between road parameters

As can be seen from Fig. 2:

$$M_x = d \cdot \tan\frac{\theta}{2} = r \cdot \sin\theta \cdot \tan\frac{\theta}{2} \tag{3}$$

$$M_y = d = r \cdot \sin\theta \tag{4}$$

The first and second derivatives are obtained for M_x, M_y, respectively, and the equation (2) is taken to obtain the acceleration interference model based on the road structure:

$$\sigma = \left\{ \frac{1}{T}\int_0^T [\frac{2v^2}{r}\sin\theta\cos\theta - \frac{1}{T}\int_0^T \frac{2v^2}{r}\sin\theta\cos\theta dt]^2 dt \right\}^{\frac{1}{2}} \tag{5}$$

Where: v is the speed; r is the radius of the flat curve.

Assuming that the radius of the circle to which the curve belongs is large, θ will be small. According to the approximation formula in the trigonometric function: sin θ~θ; cos θ~1; assuming the vehicle runs at a constant speed, then: θ = (vt) / r. Further get:

$$\sigma = \left\{ \frac{1}{T}\int_0^T [\frac{2v^2}{r}\theta - \frac{v^3}{r^2}T]^2 dt \right\}^{\frac{1}{2}} = \frac{\sqrt{3}v^3}{3r^2}T \tag{6}$$

Equation (6) is an acceleration disturbance model based on road structure under various reasonable assumptions above. If the parameters *r*, *v*, *T* are known, the acceleration interference value on the road plane can be obtained. It is generally believed that when the acceleration disturbance is greater than 1.5 m/s^2, the driving safety of the vehicle is very poor. When the acceleration interference is less than 0.7

m/s^2, the safety is better, and there is a lower possibility of potential safety hazards. The acceleration disturbance value obtained by the formula (6) can evaluate the running state of the vehicle [8].

According to the mathematical relationship of Fig. 2, the tangential line of the arc is perpendicular to the radius of the tangent point, and the azimuth difference β between the two points A and B is equal to θ; the azimuth difference between the two points A and B is β = A, B The sum of the azimuth differences of all the coordinates passed by the arc between the points; the displacement L can pass the latitude and longitude spherical distance of the two points A and B; the radius of the arc:

$$r = \frac{L}{2} \div \sin(\frac{\theta}{2}) \quad \textbf{(7)}$$

Average speed:

$$v = \frac{1}{n}\sum_{i}^{n} v_i \quad \textbf{(8)}$$

The travel time T is the time interval between A and B.

2.2 Overall Process

According to the above conclusions, the construction process of the acceleration interference model can be roughly divided into three steps: segmentation of the driving trajectory, judging the driving arc segment, and calculating the acceleration interference value. As shown in Fig. 3.

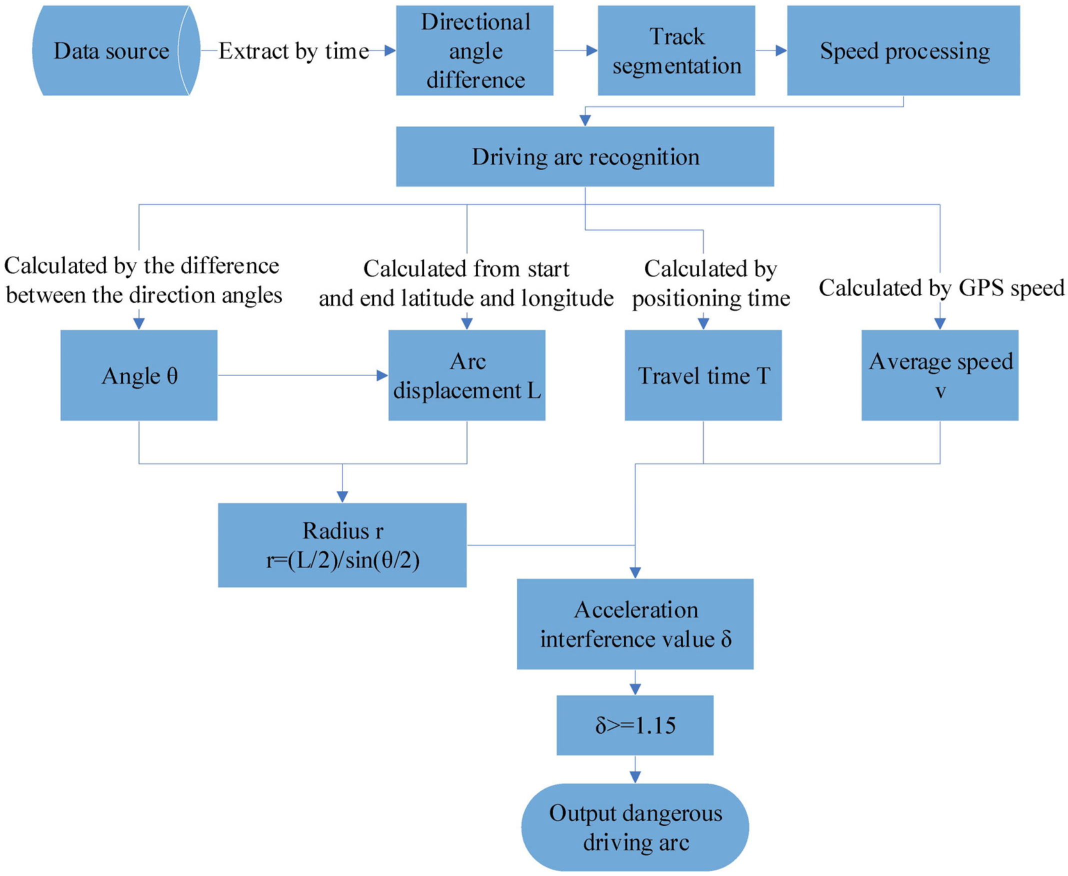

Fig. 3. Schematic diagram of the acceleration interference model

The build process is as follows:

(1) Data extraction, extracting driving trajectory data in the time period, including fields such as azimuth, longitude, latitude, and vehicle speed; (2) trajectory segmentation, calculating azimuth difference from the extracted driving trajectory data, and steering angle according to driving trajectory (ie, the azimuth difference) is larger than the threshold for segmentation, and the initial trajectory segment is

obtained; (3) the vehicle speed processing, the parking record with the vehicle speed of 0 has no meaning for the acceleration interference model, and the culling process is performed; (4) Recognize the driving arc segment. The azimuth difference further identifies the approximate arc portion of the driving process, that is, the unit driving arc segment; (5) the index calculation, for each of the identified driving arc segments, combined with the above conclusions, calculate the corresponding angle θ, displacement L, Radius r, travel time T, average speed v; (6) calculation of acceleration interference value, calculate the acceleration interference value δ from the index obtained in step (5); (7) judge the dangerous arc segment, judge the acceleration interference value δ, if $\delta \geq 1.5$, the risk factor of the arc is higher; if $\delta \leq 0.7$, the risk factor of the arc is lower. (8) Accumulate the number of times the unsafe risk is high during the selected time period.

2.3 Identification Unit Driving Arc Segment Algorithm

2.3.1 Track Segmentation

Considering the driving track as a multi-segment arc, we need to use the data to identify these arcs first.

First, a large steering (large azimuth difference θ) will make the arc unsmooth (cannot be calculated using the approximate arc theory), as shown in the following figure. Therefore, the driving trajectory is first segmented (not necessarily a circular arc segment) by using a record with a large steering.

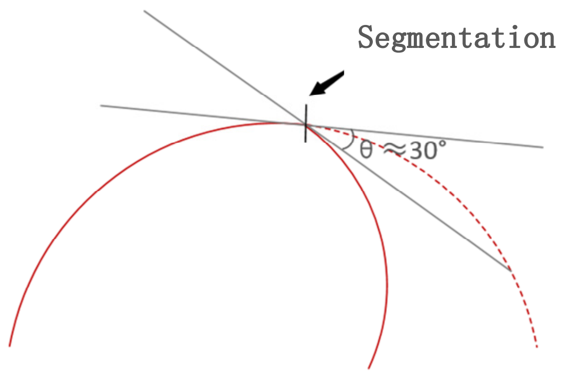

Fig. 4. Schematic diagram of large steering error

2.3.2 Driving Arc Segment Identification and Algorithm

Based on the trajectory segmentation result, after the driving trajectory segment is excluded from the larger steering condition, the circular arc segment in the trajectory is found, that is, the difference between the front azimuth angle and the rear azimuth angle is calculated by azimuth angle. Three types: the positive azimuth angle difference, negative azimuth difference, 0 azimuth angle difference will record and segment, as shown in Table 1.

After dividing according to the positive, negative, and 0 types, the arc segment of the driving arc is further divided. That is to say, within a certain period of time, the number of positive (or negative) azimuth difference (larger than a certain threshold) accounts for a large proportion (more than 70%), which is a segment of arc.

The algorithm of the circular arc segment identification of the driving track is shown in Fig. 5.

The steps for identifying the arc segment of the unit are as follows:

(a) by calculating the azimuth difference between adjacent records (classified by positive, negative, 0 type symbols), segment each initial satellite positioning data, and set the number of segments to n, starting from the number of segments $i = 1$;

(b) the number of identical symbol records in the initial stage of initialization a = the number of records in the i-th segment, the number of opposite-numbered records in the start segment $b = 0$, and the count item $k = 1$;

(c) when $i < n$, proceed to step (d); if $i >= n$, the process ends;

Table 1. positive, negative, 0 segmentation

Vehicle plate number	longitude	latitude	location_time	gps_speed	direction_angle	angle_delta
GAN F2****	115.88304	27.18382	2018-9-5 0:08	56	9	7
GAN F2****	115.88308	27.18395	2018-9-5 0:08	54	16	6
GAN F2****	115.88314	27.18408	2018-9-5 0:08	53	22	6
GAN F2****	115.88322	27.18420	2018-9-5 0:08	51	28	7
GAN F2****	115.88331	27.18431	2018-9-5 0:08	53	35	6
GAN F2****	115.88341	27.18441	2018-9-5 0:08	52	41	7
GAN F2****	115.88352	27.18450	2018-9-5 0:08	54	48	6
GAN F2****	115.88365	27.18458	2018-9-5 0:08	55	54	6
GAN F2****	115.88378	27.18465	2018-9-5 0:08	56	60	6
GAN F2****	115.88393	27.18470	2018-9-5 0:08	56	66	3
GAN F2****	115.88408	27.18475	2018-9-5 0:08	57	69	3
GAN F2****	115.88423	27.18479	2018-9-5 0:08	57	72	2
GAN F2****	115.88439	27.18483	2018-9-5 0:08	58	74	1
GAN F2****	115.88455	27.18487	2018-9-5 0:08	58	75	0
GAN F2****	115.88455	27.18487	2018-9-5 0:08	58	75	-1
GAN F2****	115.88487	27.18494	2018-9-5 0:08	58	74	-2
GAN F2****	115.88503	27.18498	2018-9-5 0:08	59	72	-4
GAN F2****	115.88518	27.18503	2018-9-5 0:08	58	68	0

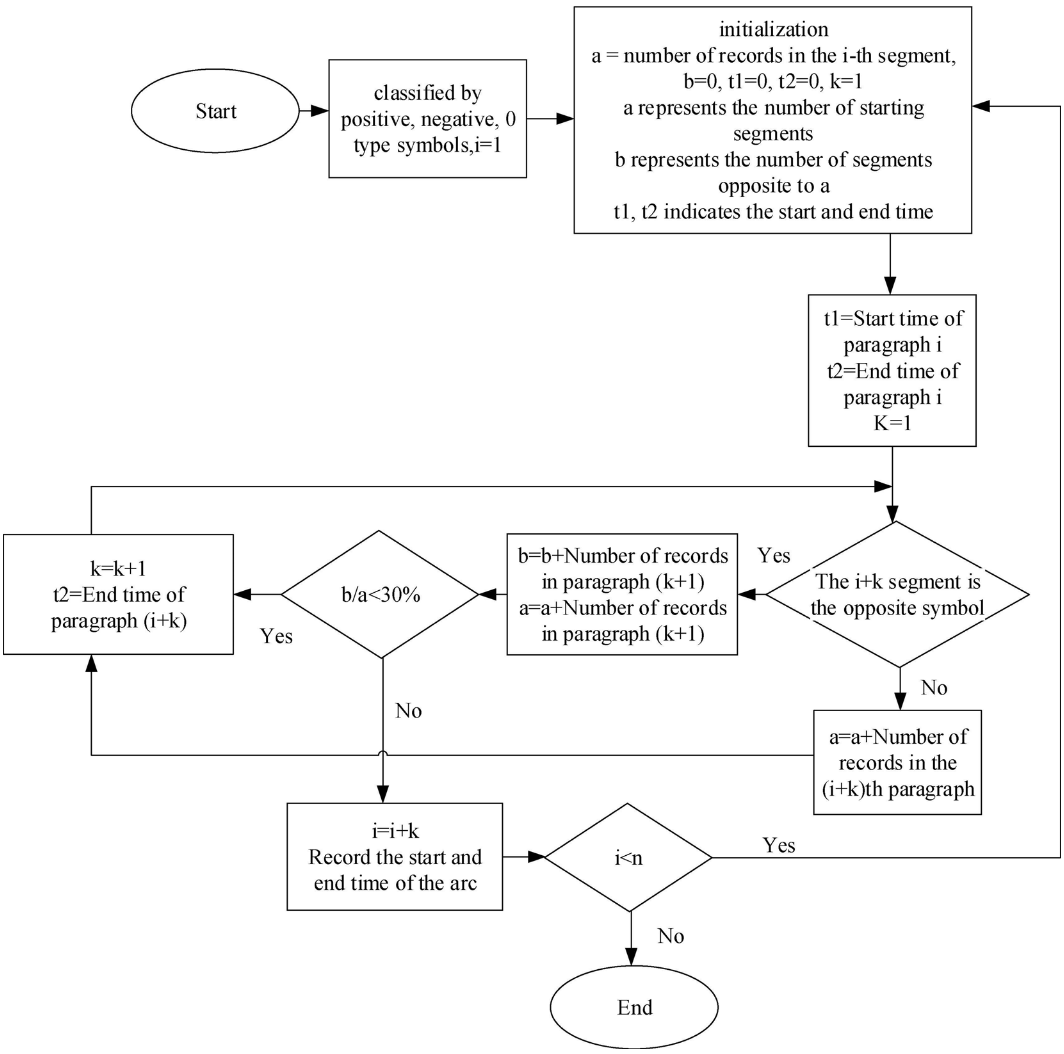

Fig. 5. Arc segment recognition algorithm flow

(d) taking the i-th segment as the starting segment, determining whether the symbol of the i + k segment is the opposite of the symbol of the i-th segment, and if so, proceeding to step (e); if otherwise, a increases the number of records of the i + k - th segment, k is incremented by 1, repeat this step;

(e) a and b simultaneously increase the number of i + k segment records, determine whether b / a is less than the set threshold α, and if so k = k + 1, a + b forms the same segment of the arc, return to step (c); Otherwise, Otherwise, from the beginning of section i to section i + k - 1, it is a section of unit driving arc. i = i + k, return to step (c) [9].

3 Specific Implementation Plan and Result Evaluation

In the following, taking the satellite positioning data of a certain vehicle to complete the unit arc segmentation as an example, calculate the vehicle index values, and finally calculate the acceleration interference value and evaluate the vehicle driving safety.

In order to fully verify the effectiveness of the proposed method, the vehicle navigation satellite positioning data used in the research and experimental verification are all from the actual operating vehicles of the road transport enterprises. According to relevant national laws and regulations, these vehicles are equipped with in-vehicle satellite positioning terminals that meet the standard requirements. When the vehicle is running, the standardized satellite positioning data is generated in real time. The fields and formats included in each data are as shown in the figure below. This paper directly uses the data returned by these vehicle terminals.

Fig. 6. Vehicle trajectory data restoration with Google satellite map

The algorithm recognizes that the vehicle “GAN B5****” is a unit driving arc during a certain period of time. calculated by the formula of spherical distance, L = 696m, the angle of the arc surface $\theta = \sum|\beta| = 1 + 2 + 3 + 3 + \ldots\ldots + 2 + 6 + 5 = 79°$, the average speed $v = (1/n)\sum v_i = 30.5$km/h = 8.47m/s, arc radius $r = L/2 \div \sin(\theta/2) = 547$m, travel time T = 17s. Finally, according to the above parameters, the acceleration interference value $\delta = 0.02$ is calculated, which is less than 0.7m/s^2, and the vehicle is safe to drive.

In the second test, the available data collected by a special vehicle experimental field was used as the input source. The original data was reduced to one latitude and longitude record per second, and the latitude and longitude coordinates of the original data were set to wps84 coordinate system, which was converted into gcj02 coordinate system by calculation.

The curved superimposed Google satellite map is shown in Fig.7.

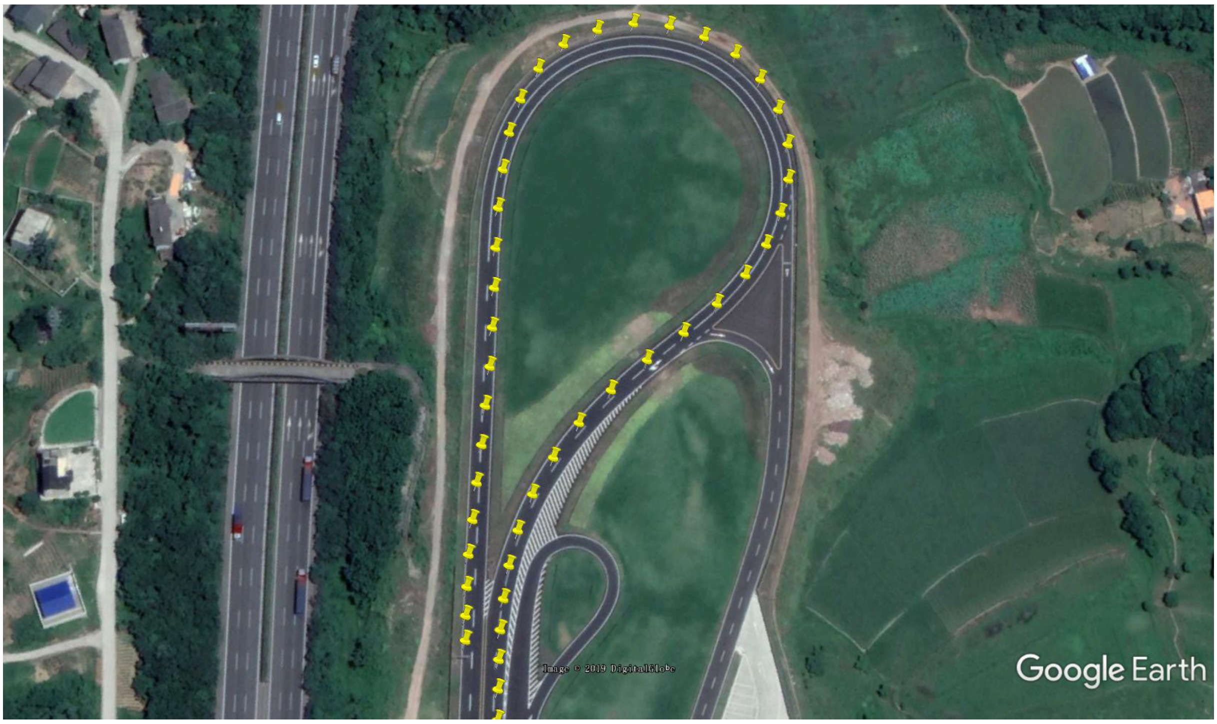

Fig. 7. The curved superimposed Google satellite map

Table 2. Example of driving arc segment identification

gps_speed	longitude	latitude	location_time	direction_angle	angle_delta
58.17	106.286	29.5330	2018/12/4 13:41	-41.56	7.63
53.21	106.286	29.5332	2018/12/4 13:41	-33.93	10.11
48.92	106.286	29.5333	2018/12/4 13:41	-23.82	11.66
50.88	106.286	29.5339	2018/12/4 13:41	58.32	14.31
50.23	106.285	29.5339	2018/12/4 13:41	72.63	13.06
51.61	106.285	29.5339	2018/12/4 13:41	85.69	14.03
51.6	106.285	29.5339	2018/12/4 13:41	99.72	15.92
52.03	106.285	29.5339	2018/12/4 13:41	115.64	16.62
51.25	106.285	29.5338	2018/12/4 13:41	132.26	15.8
…	…	…	…	…	…
49.46	106.285	29.5337	2018/12/4 13:41	148.06	14.59
48.78	106.285	29.5336	2018/12/4 13:41	162.65	10.53

The algorithm recognizes that the vehicle is in a unit driving arc during the period of “2018-12-04 13:41:20” to “2018-12-04 13:41:35”, and calculates by the spherical distance formula. L = 107.89m, the angle of the arc surface $\theta = \sum|\beta| = 214.74$, the average speed $v = (1/n)\sum v = 50.69$km/h = 14.08m/s, the radius of the arc $r = L/2 \div \sin(\theta/2) = 66.95$m, and the total length of time traveled through the arc is T = 16s. Finally, according to the above parameters, the acceleration interference value $\delta = 5.75\text{m/s}^2$, which is greater than 1.5m/s^2, so the vehicle is dangerous to drive.

We use satellite positioning data to identify the driving road alignment, and combines the acceleration interference value to calculate the driving safety risk, correspondingly, we can also compare and analyze the judgment results given by this method in the following two ways.

Comparing method 1. According to the relevant standards of China [10], the lateral acceleration of heavy vehicles should not exceed 0.3g to ensure the lateral stability of the vehicle when cornering.

Table 3. Correspondence between design speed and radius of circle curve

Design speed (km/h)	120	100	80	60	40	30	20
Curve minimum radius (general value) (m)	1000	700	400	200	100	65	30

In the specific test, the curve radius of the road section is 54 meters, and the lateral acceleration calculation formula a = v^2/r. When taking the maximum speed of the vehicle in this section, the lateral acceleration is a = 4.84m/s^2; when taking the average speed, the lateral acceleration is a = 3.67m/s^2. Both were significantly greater than 0.3g = 2.94 m/s^2. According to the experimental video of the playback, it can be seen that the vehicle has a tendency to roll over.

Comparing method 2. According to the national industry standard "Road Route Design Specification" (JTG D20-2017) [11], the correspondence between the roads driving design speed and the minimum radius of the road plane circular curve is shown in the following Table 4. When the radius of the driving route is r<65 meters, the driving speed of the vehicle should not exceed 30 km/h.

Table 4. Example of driving arc segment identification

Vehicle plate number	direction_angle	longitude	latitude	location_time	gps_speed
GAN D8****	63	114.193928	26.524793	2018/9/5 6:20:49	41
GAN D8****	68	114.194038	26.524836	2018/9/5 6:20:50	43
GAN D8****	75	114.194156	26.524868	2018/9/5 6:20:51	42
…	…	…	…	…	…
GAN D8****	130	114.194686	26.524770	2018/9/5 6:20:56	40
GAN D8****	139	114.194763	26.524693	2018/9/5 6:20:57	40
GAN D8****	149	114.194826	26.524595	2018/9/5 6:20:58	44

In the third experiment, using the satellite positioning data of the actual operation process of a vehicle, the data of a certain curve is obtained as follows:

In the specific test, the curve radius of the test section is only r = 54 m, and the driving speed of the vehicle should be significantly less than 30 km/h. The average running speed of the vehicle during the test is 50.7 km/h, and the maximum speed is 58.2 km/h. It is much higher than the speed limit. From this perspective, it can also be proved that the algorithm given in this paper can use the satellite positioning data to identify the road line type and identify the risk of the vehicle traveling at different speeds in the corner.

Using the algorithm of this paper, the vehicle "GAN D8****" is identified as a unit arc in the period of "2018-09-05 06:20:49" to "2018-09-05 06:20:57". By calculating the sum of the mileage intervals, the arc length $L = 92.20m$, the arc angle $\theta = \Sigma|\beta_i| = 5+7+\cdots+9+10 = 86°$, the average speed $v = \frac{1}{n}\sum_i^n v_i = (\frac{1}{9})*(41+43+42+\cdots+40+40+44) = 40.67km/h = 113m/s$, the arc radius $r = \frac{L}{\theta*(\pi/180)}$ $= 61.42m$, the travel time $T = 9s$. Finally, according to the above parameters, the acceleration interference value is $\delta = \frac{\sqrt{3}}{3}*\frac{V^3}{r^2}*T = 1.9850m/s^2$, which is greater than 1.5 m/s^2, so the vehicle is not safe to drive.

Similarly, the correspondence between the road driving design speed and the minimum radius of the road plane circular curve given in the national industry standard JTG D20-2017 in Table 3 is compared. When the radius of the driving route is r < 65 meters, the driving speed of the vehicle should not exceed 30 km/h.

In the specific test, The curve radius of the road segment is only r = 61.42 m, and the vehicle traveling speed should be significantly less than 30 km/h, while the average running speed of the vehicle during the actual driving is 40.67 km/h, and the maximum speed is 43 km/h. It is significantly higher than this speed limit, so it can be further confirmed that the algorithm given in this paper can use the satellite positioning data to identify the road line type and identify the risk of the vehicle traveling at different speeds in the corner.

4 Conclusion

The method for using the satellite positioning data to evaluate the driving safety of the vehicle proposed in this paper can make full use of the existing widely available satellite positioning data of the vehicle, and does not rely on the extended information such as the external geographic information for complex calculation. On the other hand, the satellite positioning data supported by the method is various, and is not limited by the brand and model of the terminal product. It is not necessary to modify the existing functions of the satellite positioning system monitoring platform, and the cost is extremely low and the threshold for popularization and application of the method is significantly reduced [12]. Combined with the actual vehicle test data collected at the vehicle test site, the recognition results given by the method are compared and analyzed by referring to the relevant national standards. Test and comparison results show that the method can achieve the expected results. The vehicle driving safety evaluation results given by this method have good application value for driver's driving behavior safety evaluation and vehicle operation safety risk assessment. It should be noted that this paper mainly considers the impact of road line type and driving speed on driving safety. In the subsequent research work, it is necessary to further consider other operating environment factors, including vehicle exterior size, weather conditions, road surface conditions, etc. And we will fully study the driving safety risk assessment method under multi-factor coupling conditions to further enhance the application value of the method.

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