Estimation method of vehicle lane by millimeter wave radar

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ABSTRACT

For the current smart high-speed scene, the millimeter-wave radar needs to give the lane number of the vehicle while outputting the lane-level target track information. Since the millimeter-wave radar cannot identify the lane line information, it is difficult to achieve the lane estimation without the help of other sensors. This paper proposes a method to quickly estimate the lane numbers of vehicles in different high-speed scenarios with the help of high-precision maps. First, it unifies the map and vehicle track coordinate system, converts the point set of lane line in WGS-84 format to the Cartesian coordinate system with the radar as the origin after coordinate transformation. Then, through Lagrange interpolation, the *X* value corresponding to the *Y* value of the vehicle on the left and right side of the lane line is obtained. Finally, the lane to which the vehicle belongs is estimated by the ratio method. The actual measurement results show that the method can quickly and accurately estimate the lane number of the vehicle in various high-speed scenarios without the help of other sensors.

Keywords: High-precision maps, lane estimation, coordinate transformation, Lagrange interpolation, ratio method

1. INTRODUCTION

On September 19, 2019, the *Outline for Building a Strong Transportation Country* issued by the Central Committee of the Communist Party of China and the State Council clearly pointed out that: strengthen the research and development of intelligent networked vehicles (smart vehicles, autonomous driving, and vehicle-road collaboration), form an independent and controllable complete industrial chain, vigorously develop smart transportation[1].

Under the policy of “transportation power + new infrastructure”, the development of the intelligent transportation industry and the promotion of the intelligentization of the transportation system will reduce the traffic problems caused by the increasingly complex road traffic scenarios, improve the operation and scheduling efficiency of the transportation system and the travel experience of the people[2].

End-of-road sensing system plays an irreplaceable sensing role in the whole intelligent transportation system, and is widely used in various fields of transportation. Among them, millimeter-wave radar, as the core sensing means, can effectively solve some problems faced by traditional camera data acquisition, for example, it is sensitive to the climate, and the detection effect is not ideal in the night, heavy rain and smog, so it is difficult to meet the practical application requirements. Therefore, millimeter-wave radar is a necessary means for intelligent and high-speed acquisition of all-weather traffic information[3-4]. It can be used to complete the whole road section target detection and road traffic incident detection.

With the in-depth implementation of China’s intelligent network technology, vehicle-road coordination is the main development trend of cities and highways in the future. Vehicle-road coordination technology puts forward higher requirements for millimeter-wave radar, which needs the radar to give the lane information of vehicles while outputting the lane-level target track, and then cooperates with the camera to realize the trigger capture function. With the lane information of vehicles, radar can also effectively count the traffic flow information of each lane, the traffic flow information of entering and leaving ramps, and detect the specific locations of abnormal events such as abnormal parking, throwing objects, congestion, etc.

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However, at present, the lane determination of vehicles by highway radar is mostly realized by camera at the edge-computing node where radar and camera are fused[5-6]. However, only millimeter-wave radar is used to estimate the target lane. At present, there is only the intersection traffic radar[7], because the intersection is a straight road. In the early stage, by calibrating the radar position and the azimuth angle, the lane to which the vehicle belongs can be determined by the relationship between the X value of the vehicle and the X value of the radar origin in the rectangular coordinate system. However, this method has great limitations and can only be applied to straight road scenes. However, the expressway scene is complex, and there are also curved high-speed, service area, ramp, emergency parking zones, etc. It is impossible to judge the lane where the target is located only by the target X value. It is difficult to independently determine the lane information of the vehicle depending on the radar's own information.

In this paper, a brand-new method for calculating the lanes of high-speed vehicles is proposed, which is realized by means of high-precision maps of highway lane edges. Because the storage space of the radar itself is small, it only needs to select the sparse point set to go to the edge of each two lanes. The vehicle position information and lane line information detected by radar are converted into the same rectangular coordinate system, and then the X coordinates of the two-lane edges corresponding to the Y value of the vehicle position are calculated by interpolation, and the lane of the target vehicle is obtained by the relative relationship between the lane line and the X value of the vehicle. This method does not need other sensor information, but only needs the prior information of high-speed map to estimate the lane to which the vehicle belongs. Moreover, this method takes up less radar memory, is simple to implement, requires less calculation and has high reliability.

2. LANE ESTIMATION METHOD BASED ON MAP

The target location information detected by radar is matched with the map, and then the lane where the target is located can be obtained, but the accuracy of the map is high enough. High-precision maps are usually measured by RTK, LIDAR, camera and other multi-sensors, and the accuracy can reach the level of 10 cm[8], which can fully meet the vehicle position matching, so as to estimate the lane to which the vehicle belongs.

There are many coordinate system formats for high-precision maps, including WGS-84 coordinate system, GCJ-02 coordinate system, BD-09 coordinate system, etc. For radar, the target measurement is usually done in the space polar coordinate system, and the subsequent target measurement data is done in the rectangular coordinate system, that is, the target track output by radar is based on the rectangular coordinate system, which is inconsistent with the high-precision map coordinate system. Therefore, it is necessary to carry out spatial registration first, and transform them into the same coordinate system. In order to simplify the calculation, we use the rectangular coordinate system of radar.

Taking the curved high-speed as an example, as shown in Figure 1, two solid lines are two edges of the upward lane, and three dotted lines are lane edges. The target position is T point, the line AB is parallel to the X-axis, and the line CD is perpendicular to the road edge.

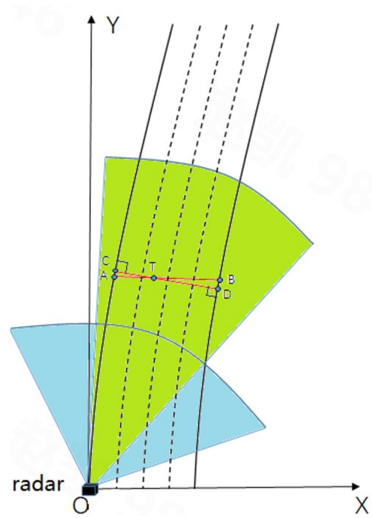

Figure 1. Schematic diagram.

If we want to calculate the lane number of the target, we need to get the distance from point C to point T. Under normal circumstances, it is very complicated to calculate the length of line CT, that is, to calculate the shortest distance from point T to the lane edge. Here, we use the triangle similarity principle to find the length of line AT. The principle is as follows:

Many detours will be designed on expressways due to terrain, anti-fatigue driving and other reasons. However, in order to keep safe driving in detours, the design of curvature radius is generally large. According to this, the detour can be divided into many segments, and it is approximately considered that the two edges of the one-way lane in the segment are approximately parallel. Therefore, we can approximately think that ∠ACT=∠BDT=90°, and because ∠ATC=∠BTD, it can be obtained from similar triangles's judgment condition: △ACT∽△BDT, which can be obtained from similar triangles's theorem:

$$\frac{L_{CT}}{L_{AT}} = \frac{L_{CD}}{L_{AB}} \tag{1}$$

among them, L_{CT} is the distance from point C to point T, L_{AT} is the distance from point A to point T, L_{CD} is the distance from point C to point D, and L_{AB} is the distance from point A to point B, namely:

$$rate = \frac{L_{CT}}{L_{CD}} = \frac{L_{AT}}{L_{AB}} \tag{2}$$

among them, *rate* is the distance ratio relationship between L_{CT} and L_{CD}. As the width of each lane is known and fixed, as long as *rate* is obtained, the lane number of the current target can be calculated through the relative distance relationship with each lane line. The specific derivation is as follows:

Assuming that the expressway has N lanes in one direction, and the width of each lane is I_1, I_2 … I_N, then

$$I_{\Sigma} = \sum_{i=1}^{N} I_i \tag{3}$$

where I_{Σ} is the total width of one-way lane.

The ratio of the distance from the right edge of each lane to the leftmost edge to the sum of the widths of all one-way lanes is:

$$rate_i = \frac{I_i}{I_{\Sigma}} \tag{4}$$

As shown in Figure 1, assuming that the coordinates of point T is (X_0, Y_0), point A is (X_{left}, Y_0) and point B is (X_{right}, Y_0). Use X_{left} and X_{right} values to calculate the proportion of lanes occupied by vehicles *rate*:

$$rate = \frac{X_0 - X_{left}}{X_{right} - X_{left}} \tag{5}$$

According to the value of *rate*, determine the lane to which the vehicle belongs:

If $0 \le rate < \frac{\sum_{i=1}^{1} I_i}{I_{\Sigma}}$, it is judged as lane 1;

If $\frac{\sum_{i=1}^{1} I_i}{I_{\Sigma}} \le rate < \frac{\sum_{i=1}^{2} I_i}{I_{\Sigma}}$, it is judged as lane 2;

If $\frac{\sum_{i=1}^{h-1} I_i}{I_\Sigma} \le rate < \frac{\sum_{i=1}^{h} I_i}{I_\Sigma}$, it is judged as lane h,

where $h \in N$.

Specifically, when the vehicle rides over the innermost lane edge or the outermost lane edge, it may cause the filter track to deviate into the green belt or shoulder, and the following special treatment can be done:

(1) if the target falls into the green belt and *rate* satisfies $\alpha \le rate < 0$, the lane to which the target belongs will be judged as lane 1, and α can be adjusted according to the actual situation.

(2) If the target falls on the shoulder of the road, that is $1 < rate \le 1 + \beta$, the lane to which the target belongs is judged as the emergency lane, and β can be adjusted according to the actual situation.

(3) This method can also eliminate the targets outside the lane and pull the targets out of the lane back into the lane.

3. SPECIFIC STEPS OF LANE ESTIMATION

3.1 Step flows

Figure 2 shows the main flow chart of calculating the lane number of the vehicle by millimeter-wave radar based on high-precision latitude and longitude map.

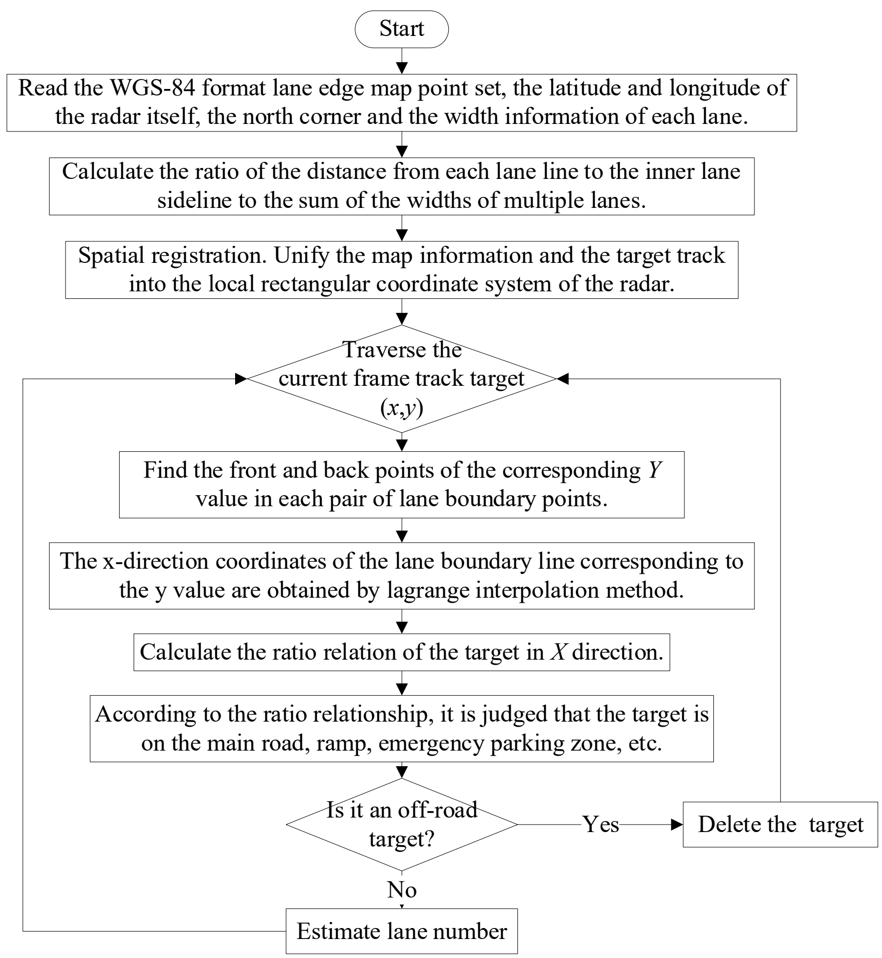

Figure 2. Flow chart of lane estimation.

3.2 Spatial registration

Taking WGS-84 coordinate system as an example, the space registration coordinate transformation equation is as follows:

For a certain point in space, the conversion relationship from WGS-84 coordinate system (*L,B,H*) to ECEF coordinate system (*X,Y,Z*) is as follows[9-10]:

$$\begin{cases} X = (N+H)\cos B \cos L \\ Y = (N+H)\cos B \sin L \\ Z = [N(1-e^2)+H]\sin B \end{cases} \tag{6}$$

where N is the unitary circle curvature radius of the point, $N = a/\sqrt{1-e^2\sin^2 B}$; e is the first eccentric heart rate, $e^2 = \left(a^2-b^2\right)/a^2$, a =6378137 m is the major axis of the earth, and b =6356755 m is the minor axis of the earth. In the ECEF coordinate system, the origin O is the center of mass of the earth, the X axis extends through the intersection of the prime meridian (0 degrees longitude) and the equator (0 degrees latitude), the Z axis extends through the North Pole (i.e. coincides with the earth's rotation axis), and the Y axis passes through the equator and 90 degrees longitude according to the right-handed coordinate system.

The calculation equation for transforming ECEF coordinate system into ENU coordinate system on the surface is as follows:

$$\begin{cases} E = -\sin L_0 \cdot (X - X_0) + \cos L_0 \cdot (Y - Y_0) \\ N = -\sin B_0 \cos L_0 \cdot (X - X_0) - \sin L_0 \sin B_0 \cdot (Y - Y_0) + \cos B_0 \cdot (Z - Z_0) \\ U = \cos B_0 \cos L_0 \cdot (X - X_0) + \cos B_0 \sin L_0 \cdot (Y - Y_0) + \sin B_0 \cdot (Z - Z_0) \end{cases} \tag{7}$$

Where (X_0, Y_0, Z_0) is the coordinate of the detection radar in ECEF coordinate system, and (L_0, B_0, H_0) is the coordinate of the detection radar in WGS-84 coordinate system.

The latitude and longitude information of radar and high-precision map is converted into ENU coordinates by equations (6) and (7), and then the ENU coordinates are rotated by $-\varphi$ according to azimuth angle φ of radar, and converted into radar OXYZ coordinate system. The conversion formula is as follows:

$$\begin{cases} x = E\cos\psi + N\sin\psi \\ y = N\cos\psi - E\sin\psi \\ z = U \end{cases} \tag{8}$$

Where, $\psi = -\varphi$ is the azimuth angle of the radar, (x, y, z) is the coordinate of the radar OXYZ coordinate system.

3.3 Lagrange interpolation

The Lagrange three-point interpolation method can be used to calculate the high-precision data to the low-precision time point. Its specific algorithm principle is described as follows:

Assuming that the measured data at the time t_{k-1}, t_k, t_{k+1} are X_{k-1}, X_k, X_{k+1}, the measured value at the moment of t_i ($t_{k-1} < t_i < t_{k+1}$) is calculated as follows:

$$X_i = \frac{(t_i - t_k)(t_i - t_{k+1})}{(t_{k-1} - t_k)(t_{k-1} - t_{k+1})} \times X_{k-1} + \frac{(t_i - t_{k-1})(t_i - t_{k+1})}{(t_k - t_{k-1})(t_k - t_{k+1})} \times X_k + \frac{(t_i - t_{k-1})(t_i - t_k)}{(t_{k+1} - t_{k-1})(t_{k+1} - t_k)} \times X_{k+1} \tag{9}$$

As shown in Figure 1, if we want to get the value of L_{AT} and L_{AB}, we need to get the coordinates of point A and point B. Because the lane line is a discrete point set, it needs interpolation. When the density of lane line points is high, the lane line between two adjacent points can be approximately considered as a straight line, and the coordinates of point A and point B can be obtained by linear interpolation. If the density of lane line point set is small, a big error will be generated simply by linear interpolation. It is necessary to calculate the high-precision lane line to the Y value corresponding to the target T by Lagrange three-point interpolation method, and get the X coordinate values of point A and point B.

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1 Lane estimation of high-speed real scene

Figure 3 shows the real-time monitoring picture of a two-way 8-lane (including emergency lane) curve scene camera. At this moment, there are two vehicles in the approaching lane and one vehicle in the departing lane in the detection range. Make lane estimation for the vehicles in the radar detection range on this picture. It is stipulated that the upward lane numbers are 1-4 from the inside to the outside, and the downward lane numbers are 11-14 from the inside to the outside. As shown in Figure 4, the lane estimation results at this moment match the picture.

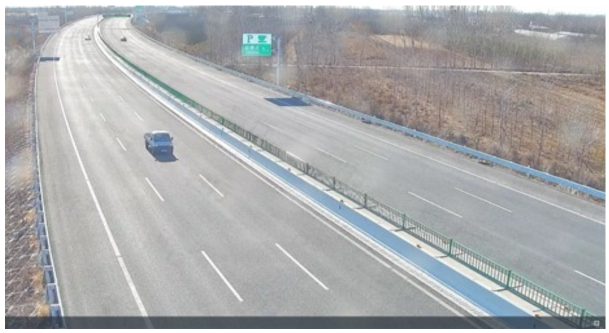

Figure 3. Expressway photo information.

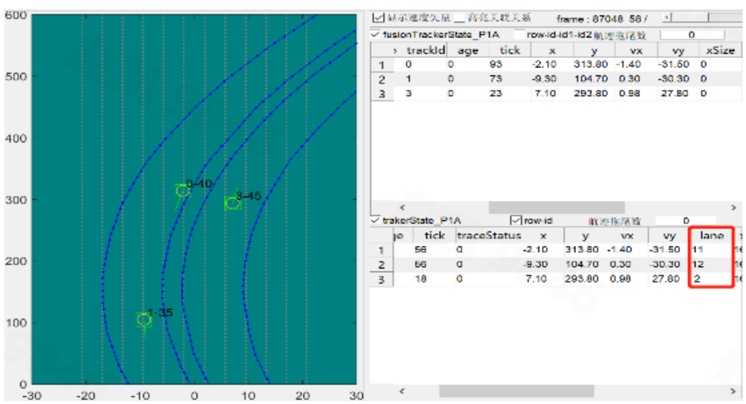

Figure 4. Radar output information.

Under different road scenes (straight high-speed, curve high-speed, ramp and emergency parking zones) for a period of time, through data and video playback, this paper compares whether the lane number of vehicles output by radar matches the actual situation, and counts the estimated correct and wrong vehicles. Figure 5 is a straight high speed scene, Figure 6 is a curve high-speed scene, and Figure 7 is a ramp scene. Figure 8 shows the scene with emergency parking zones.

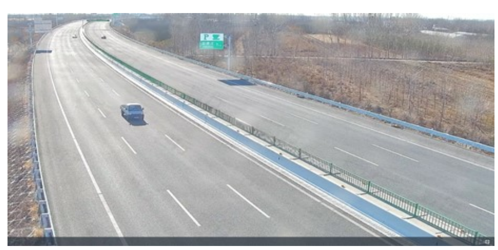

Figure 5. Straight high-speed scene. Figure 6. Curved high-speed scene.

Figure 7. Ramp high-speed scene.

Figure 8. Emergency parking zones scene.

4.2 Results statistics

As shown in Table 1, statistics of passing vehicles in a period of time are made in the scenes of straight high-speed, curve high-speed, ramp and emergency parking zones. The lane recognition accuracy is very high. A few wrong vehicles are identified because of radar measurement errors. The experimental results fully show that this method can accurately and reliably estimate the lane number of vehicles in different lane scenes.

Table 1. Result statistics.

Scene	**Statistics time (H)**	**Number of vehicles**	**Accuracy rate (%)**
Straight high-speed	1	187	98.93
Curve high-speed	1	192	98.96
Ramp	2	55	98.18
Emergency parking zones	10	9	100

5. CONCLUSION

In this paper, a method of estimating vehicle lane number by millimeter-wave radar based on high-precision map is proposed, and the whole lane of high-speed vehicles is estimated. This method is used in all kinds of high-speed scenes, and has the advantages of good real-time, high accuracy and versatility.

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