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Modeling the Special Intersection for Enhanced Digital Map

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Abstract—**The enhanced digital map is of great significance for various Intelligent Transportation System (ITS) applications and services, especially at the lane-level. This requirement motives the development of road modeling in the enhanced digital map at the lane-level. However, previous enhanced digital maps do not provide detailed modeling of special intersections which are covered by vegetation in the central region. In this paper we propose a novel lane-level road model for this special intersection scenario. The proposed intersection model can be considered into two levels: topological structure and geometrical structure. Topological structure of this model helps describe the connectivity, turn restrictions and other attributes of the special intersection in the real world. Geometrical structure of this model helps describe the virtual lanes of the internal part of the special intersection using cardinal spline, which better approximates the real vehicle trajectory at the intersection. The proposed intersection model has been verified and evaluated through experiments. The results demonstrate the effectiveness of the proposed intersection model in representing the lane-level topological and geometrical details of special intersection which is covered by vegetation in its central region.**

Key words—**enhanced digital map, lane-level, intersection model, cardinal spline**

I. INTRODUCTION

Nowadays, there has been a significant amount of progress in developing Intelligent Transportation System (ITS) applications and services such as advanced driver assistance systems, automated vehicle navigation systems and fleet management systems. These applications and services require accurate and reliable position information of vehicles on different road traffic scenarios [1-2]. An enhanced digital map is usually considered as an additional measurement that can provide various information on the local environment of the vehicles for these applications and services [3-4]. Therefore, accurate and reliable enhanced digital maps are crucial to the further development of intelligent transportation system applications and services. In order to reach high performance solutions to handle the challenges of the complex road traffic situations, a specific research interest aiming at improving the accuracy of both the vehicle positioning and enhanced digital maps to reach the lane-level is attracting more and more attentions. The vehicle positioning resolution has made significant progress with local differential station (DGPS) to reach the accuracy at the lane-level [5]. However, there is still considerable room for improvement in terms of accuracy of most of the existing enhanced digital maps.

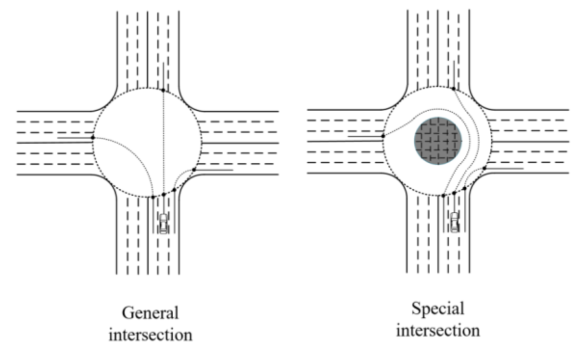

Fig. 1. Two different types of intersection

Road modeling is the core part of generating enhanced digital maps. The model of an enhanced digital map is used to abstract and simplify the real road network. However, most of conventional researches concentrate more on the information about the representation of road geometry with curve elements, where the intersections are not highly concerned. As an important element for road network representation, intersection plays a greatly significant role to describe the connectivity and turn restrictions of all the lanes. In the general models that are adopted by commercial digital maps, the intersection is always omitted or simplified. For example, the Kiwi model defines the intersection as a logical component to help describe the connectivity and turn restrictions of an intersection in the real world, whereas the geometrical description of its internal part is ignored [6-7]. The shortcoming of this model may make poor performance of ITS applications and services at intersections. In order to overcome this limitation and enrich the road model for the intersection, some researchers developed the track road to approximate the real vehicle turning trajectory and describe the geometric details of an intersection [7-8]. However, these models only provide alternative methods for the topological and geometrical structure of general intersections at the lane-level and cannot be applied to the special intersection which is covered by vegetation in its central region (see Fig.1).

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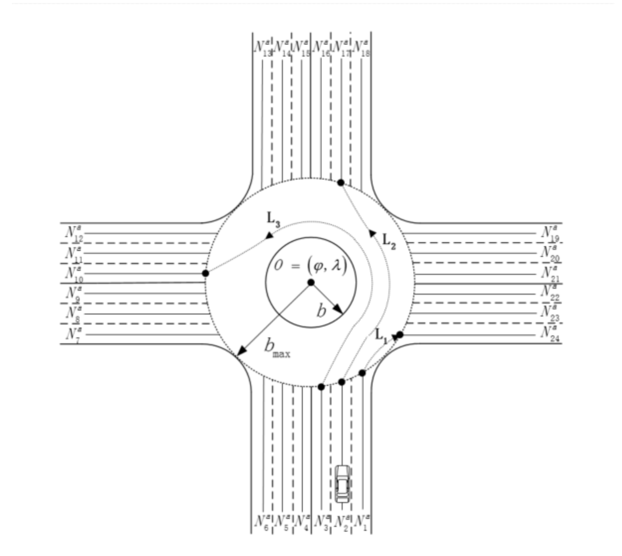

Fig. 2. The schematic diagram of the lane-level road model for the special intersection

Additionally, similar conceptions were applied in these recently developed lane-level intersection models, where the virtual lanes were generated using various types of spline curve. It is important to select an appropriate spline curve to represent geometry structure of the virtual lanes in order to balance the accuracy and data storage of the intersection model well. Currently, B-spline curve and Hermite spline curve were widely selected to build road models in previous literatures [9-11]. A B-spline-based road model has an advantage that the change of local control points do not affect the entire shape of lanes, which makes local modification possible. However, it is difficult to extract geometry information (the curvature and the tangent angle) from the function of the B-spline curve. Therefore, the availability of the B-spline model is poor. Moreover, the Hermite spline-based road model also has some disadvantages such as that interpolation polynomial can only be used when the function value and derivative value of the interpolation polynomial at all interpolation points are known, which results in large amounts of data that need to be stored and processed. Therefore, it is difficult for Hermite spline model to balance the accuracy and data storage of the road model well.

In this paper, we propose a novel lane-level road model for the special intersection which is covered by vegetation in its central region. The proposed intersection model can be considered into two levels: topological structure and geometrical structure. Topological structure of this model helps describe the connectivity, turn restrictions and other attributes of the special intersection in the real world. Geometrical structure of this model helps describe the virtual lanes of the internal part of the special intersection using cardinal spline, which better approximates the real vehicle trajectory at the intersection. The cardinal spline is specified by a series of control points and tension parameters. A gradual optimization algorithm is proposed to determine reasonable control points and optimal tension parameters for different traffic situations at the special intersection. Selection of reasonable control points can improve data storage efficiency and optimal tension parameters can satisfy a desired accuracy. Consequently, the lane-level intersection model proposed in this paper realizes a near-optimal balance between the accuracy and data storage of the special intersection.

The remainder of this paper is organized as follows. In Section 2, the lane-level road model for the special intersection is presented in detail. Then, the gradual optimization algorithm for this intersection model is proposed in Section 3. Experimental results are provided in Section 4. Section 5 is devoted to the conclusion and future work.

II. LANE-LEVEL ROAD MODEL FOR THE SPECIAL INTERSECTIONG

The lane-level road model for the special intersection can be considered into two levels: topological structure and geometrical structure. Topological structure of this model helps describe the connectivity, turn restrictions and other attributes of the special intersection in the real world. Geometrical structure of this model helps describe the virtual lanes of the internal part of the special intersection using cardinal spline, which better approximates the real vehicle trajectory at the intersection. Then we will describe these two aspects in more detail.

A. Topological structure of the model

Under various considerations, the lane-level road model for the special intersection is defined as follows:

$$\mathbf{M} = (\mathbf{Q}, \mathbf{V}) \tag{1}$$

Where $\mathbf{Q}$ indicates the set of basic attributes of the special intersection, $\mathbf{V}$ indicates the set of the virtual lanes inside this intersection. Fig.2 shows the schematic diagram of the lane-level road model for the special intersection.

The set of basic attributes of the special intersection $\mathbf{Q}$ is defined as follows:

$$\mathbf{Q} = (N_c, O, b, b_{\max}, \mathbf{U}) \tag{2}$$

Where N_c indicates the serial number of this intersection, O indicates the coordinates of the center point of this intersection, $O = (\varphi, \lambda)$ in which φ is the latitude of the center point and λ is the longitude of the center point, b is the radius of the vegetation area in the middle of this intersection, $b_{\max}$ is the maximum radius of this intersection. $\mathbf{U}$ indicates the set of actual lanes which are connected to this intersection, $\mathbf{U} = \{N_1^a, N_2^a, \cdots, N_d^a\}$, in which d indicates the total number of connected actual lanes and N^a indicates the serial number of connected actual lanes.

The set of the virtual lanes inside this intersection $\mathbf{V}$ is defined as follows:

$$\mathbf{V} = (\mathbf{L}_1, \mathbf{L}_2, \cdots, \mathbf{L}_m) \tag{3}$$

Where m indicates the total number of connected virtual lanes,

$\mathbf{L}$ indicates the set of basic attributes of the virtual lane. Additionally, $\mathbf{L}$ can be further expressed as：

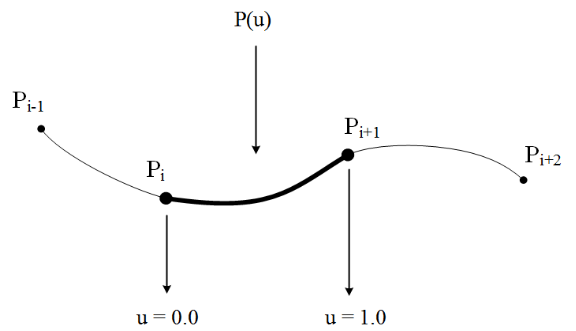

Fig. 3. The spline segment when u ranges from 0 to 1 between P_i and P_{i+1}

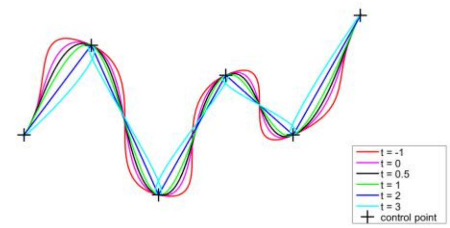

Fig. 4. The cardinal spline with six different values for the tension parameter pass through the same series of control points

$$\mathbf{L} = (N^v, N^a_{out}, N^a_{in}, \mathbf{G}, \mathbf{A}) \tag{4}$$

Where N^v indicates the serial number of this virtual lane inside the intersection, N^a_{out} and N^a_{in} indicate the serial number of actual departure lane and actual enter lane which are connected to this virtual lane, respectively.

$\mathbf{G}$ is the set of control points that describe the geometry structure of this virtual lane, $\mathbf{G} = \{(x_1, y_1), \cdots, (x_n, y_n)\}$, in which n indicates the total number of control points and x, y indicate the latitude and longitude of control points respectively. And $\mathbf{A}$ is the parameter set of the spline curve fitting this virtual lane.

B. Geometrical structure of the model

Geometrical structure of the model helps describe the virtual lanes of the internal part of the special intersection using cardinal spline, which better approximates the real vehicle trajectory at the intersection. In this paper, we choose the cardinal spline to represent geometrical structure of the model. The cardinal spline is specified by a series of control points and tension parameters. A gradual optimization algorithm will be introduced in detail in next section which determines reasonable control points and optimal tension parameters for different traffic situations at the special intersection.

Currently, spline curve can generally be divided into two categories: approximating spline and interpolating spline. The cardinal spline is a family of interpolating spline [11-12]. To the best of the author's knowledge, the cardinal spline has been researched for a long time in the field of the CAD/CAM industry and the cardinal spline representation of the road geometry structure is rarely applied in the field of road modeling in the previous literatures.

The cardinal spline is specified by a series of control points and tension parameters. A cardinal spline passes smoothly through each control point. The cardinal spline is a sequence of individual piecewise cubic curves joined to form a larger curve, and each cardinal spline segment is defined by four control points $P_{i-1}, P_i, P_{i+1}, P_{i+2}$, with the curve drawn only from P_i to P_{i+1}. Formulated such that the tangent at each control point P_i is calculated using the previous and next control point on the spline, without being given by human. A single cardinal spline segment can be completely determined by four consecutive control points, in which the middle two control points are the endpoints of cardinal spline segment and the other two control points are used to calculate the tangents at the endpoints of this cardinal spline segment. Let us suppose that $P_{i-1}, P_i, P_{i+1}, P_{i+2}$ are given four consecutive control points (each of them has x and y values) and $P(u)$ is a parametric cubic polynomial between the control points P_i and P_{i+1} (u is the parameter). Hence the boundary condition for establishing a single cardinal spline segment using four points from P_{i-1} to P_{i+2} is:

$$\left.\begin{aligned} &P(0) = P_i \\ &P(1) = P_{i+1} \\ &P'(0) = (1-t) \times (P_{i+1} - P_{i-1}) \\ &P'(1) = (1-t) \times (P_{i+2} - P_i) \end{aligned}\right\} \tag{5}$$

Where $P(0)$ and $P(1)$ are the position vectors of $P(u)$ at the two endpoints of the spline segment between P_i and P_{i+1}, respectively. And u is the parameter of the spline segment and ranges from 0 to 1 between P_i and P_{i+1} (see Fig.3). $P'(0)$ and $P'(1)$ are the tangent vectors of $P(u)$ at the two endpoints of the spline segment between P_i and P_{i+1}, respectively. The parameter t is a tension parameter which affects the tightness of the cardinal spline. When t = 0, the cardinal spline curve is called Catmull Rom spline curve.

Then, after a series of decomposition of the equation (5), the cardinal spline segment between the control points P_i and P_{i+1} is given as follows:

$$\left.\begin{aligned} &x(u) = A_0^i + A_1^i u + A_2^i u^2 + A_3^i u^3 \\ &y(u) = B_0^i + B_1^i u + B_2^i u^2 + B_3^i u^3 \\ &(0 \le u \le 1) \end{aligned}\right\} \tag{6}$$

Where:

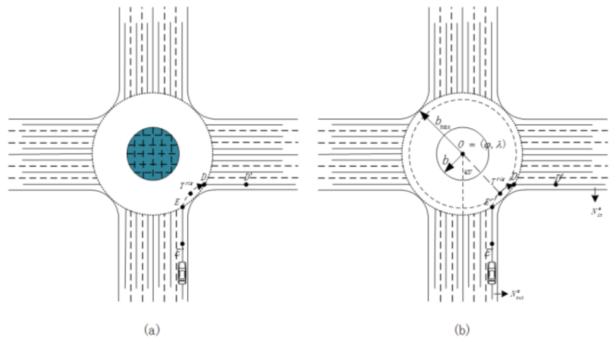

Fig. 5. The schematic diagram of the right-turn situation

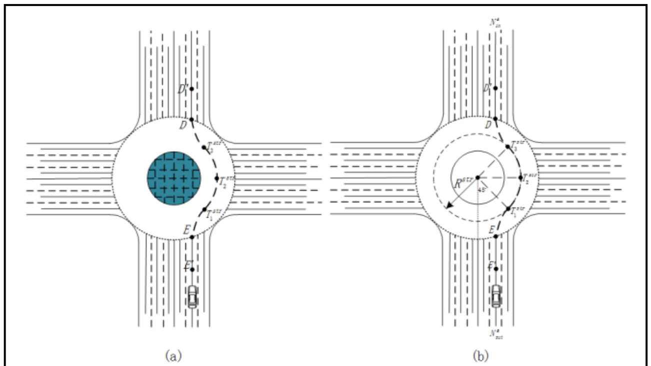

Fig. 6. The schematic diagram of the go-straight situation

$$\left.\begin{aligned}
&A_0^i = x_i \\
&A_1^i = -sx_{i-1} + sx_{i+1} \\
&A_2^i = 2sx_{i-1} + (s-3)x_i + (3-2s)x_{i+1} - sx_{i+2} \\
&A_3^i = -sx_{i-1} + (2-s)x_i + (s-2)\mathrm{x}_{i+1} + sx_{i+2} \\
&B_0^i = y_i \\
&B_1^i = -sy_{i-1} + sy_{i+1} \\
&B_2^i = 2sy_{i-1} + (s-3)y_i + (3-2s)y_{i+1} - sy_{i+2} \\
&B_3^i = -sy_{i-1} + (2-s)y_i + (s-2)y_{i+1} + sy_{i+2} \\
&\ s = 1 - t/2
\end{aligned}\right\}$$

The cardinal spline with different values for the tension parameter will produce different curves through a given series of control points. As shown in Fig.4, the cardinal spline with six different values for the tension parameter pass through the same series of control points. The tension parameter t is shown on the bottom right of Fig.4 for different values.

Note that the cardinal spline in the preceding figure share the same tangent line at the starting point which is the line drawn from the starting point to the next point along the curve. Likewise, the shared tangent at the ending point is the line drawn from the ending point to the previous point on the curve. The tangent line at other points is parallel to the line drawn from the previous point to the next point along the curve.

III. GRADUAL OPTIMIZATION ALGORITHM

A gradual optimization algorithm is proposed to determine reasonable control points and optimal tension parameters for different traffic situations at the special intersection. We select reasonable control points for the cardinal spline according to different traffic situations, which can improve data storage efficiency of this intersection model. In addition, the value of the tension parameter for each individual cardinal spline segment will be gradually adjusted to satisfy a desired accuracy until the error between the roadway data points and the cardinal spline meets an acceptable range, which better approximates the real the vehicle trajectory at the special intersection. In this paper, a probe vehicle equipped with a single-enclosure GPS+INS positioning system measures the roadway data points of the special intersection and acquired data will be processed manually to remove the outliers.

In general circumstances, traffic situations at the special intersection can be divided into three categories: turn right, turn left and go straight. For these three different traffic situations, we separately select different points as control points of the cardinal spline which can represent geometrical structure of this intersection model. In (4), **G** can be further expressed as：

$$\mathbf{G} = \begin{cases} \left\{E', E, T^{rig}, D, D'\right\} & \textit{turn right} \\ \left\{E', E, T_1^{str}, T_2^{str}, T_3^{str}, D, D'\right\} & \textit{go straight} \\ \left\{E', E, T_1^{left}, T_2^{left}, T_3^{left}, D, D'\right\} & \textit{turn left} \end{cases} \tag{7}$$

The selection process of control points for right-turn situation and go-straight situation at the intersection is described in detail later. Similar process can be ascertained for left-turn situation.

A. The situation of right-turn

For the right-turn situation, **G** can be specifically expressed as follows:

$$\mathbf{G} = \left\{E', E, T^{rig}, D, D'\right\} \tag{8}$$

As shown in Fig.5 (a), $\mathbf{G} = \left\{E', E, T^{rig}, D, D'\right\}$ is a set of control points arranged in order by the right-turn trajectory of the vehicle at the special intersection.

Where E is the endpoint of the lane which enters into the intersection. D is the starting point of the lane which drives out the intersection. E' is the control point of 10 m apart from the point E on the enter lane. D' is the control point of 10 m apart from the point D on the departure lane

T^{rig} is a special control point selected for right-turn situation. And T^{rig} is the point at which a straight line with a 45-degree angle to the centerline is intersected by a circle with the point O as a center point and a radius of $(b+10)$ m. The specific details as shown in Fig.5 (b).

Then, we use the above series of points as the control points of the cardinal spline and gradually adjust the value of the tension parameter for each individual cardinal spline segment until the error between the given roadway data points and the cardinal spline meets an acceptable range, which better approximates the real right-turn trajectory of the vehicle at the intersection.

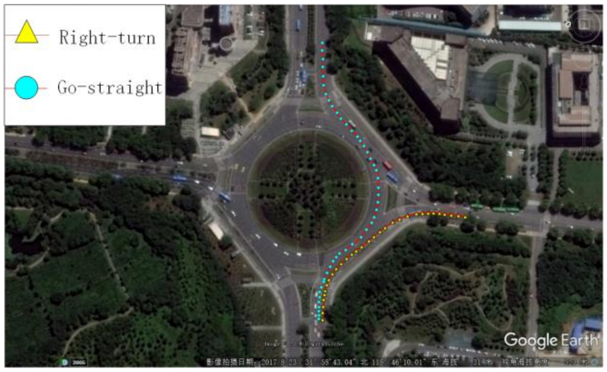

Fig. 7. The result of the cardinal spline road modeling-based on the gradual optimization algorithm under the right-turn situation

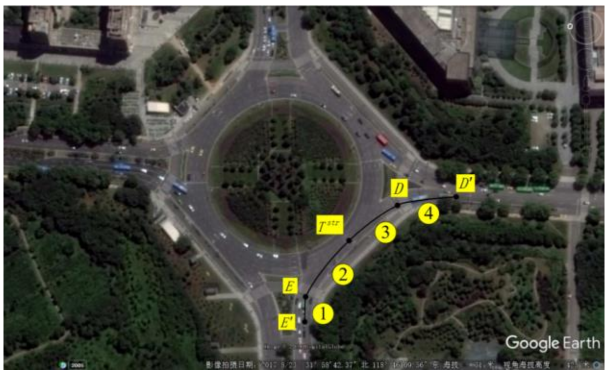

Fig. 8. The result of the cardinal spline road modeling-based on the gradual optimization algorithm under the go-straight situation

B. The situation of go-straight

For the go-straight situation, $\mathbf{G}$ can be specifically expressed as follows:

$$\mathbf{G}=\left\{E',E,T_1^{str},T_2^{str},T_3^{str},D,D'\right\} \tag{9}$$

As shown in Fig.6 (a), $\mathbf{G}$ is a set of control points arranged in order by the go-straight trajectory of the vehicle at the special intersection. Where E is the endpoint of the lane which enters into the intersection. D is the starting point of the lane which drives out the intersection. E' is the control point of 10 m apart from the point E on the enter lane. D' is the control point of 10 m apart from the point D on the departure lane.

$T_1^{str},T_2^{str},T_3^{str}$ are special control points selected for go-straight situation. T_1^{str} is the point at which a straight line with a 45-degree angle to the centerline is intersected by a circle with the point O as a center point and a radius of $(b+6)$ m. T_2^{str} is the point at which a straight line with a 90-degree angle to the centerline is intersected by this circle. T_3^{str} is the point at which a straight line with a 135-degree angle to the centerline is intersected by this circle. The specific details as shown in Fig.6 (b).

Then, we use the above series of points as the control points of the cardinal spline and gradually adjust the value of the tension parameter for each individual cardinal spline segment until the error between the given roadway data points and the cardinal spline meets an acceptable range, which better approximates the real go-straight trajectory of the vehicle at the intersection.

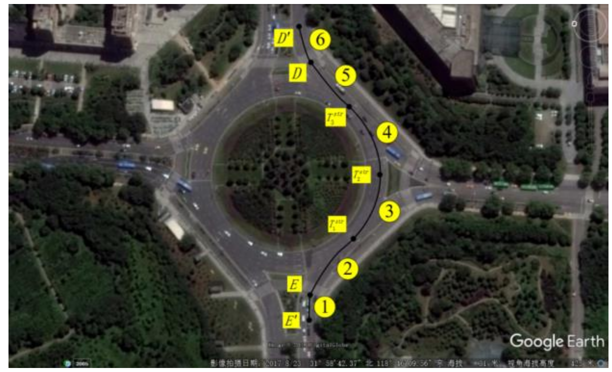

Fig. 9. The result of the cardinal spline road modeling-based on the gradual optimization algorithm under the right-turn situation

IV. EXPERIMENTAL RESULTS

A. Experiment setup

To evaluate the performance of the proposed lane-level road model for the special intersection, experiments were carried out on a Chery TIGGO5 SUV vehicle. The raw roadway data points of the special intersection was collected using the probe vehicle equipped with a GPS+INS vehicle positioning system (NovAtel SPAN-CPT system). NovAtel SPAN-CPT system is an accurate and reliable GPS+INS vehicle positioning system, which can provide accurate positioning information via post-processing even under adverse environments [13]. The specifications of NovAtel SPAN-CPT system are summarized in Table I. In this paper, the probe vehicle was driven at a stationary driving speed of 30 km/h to 50 km/h along the centerline of the lane.

Table I

The specifications of NovAtel SPAN-CPT system

Measurement	Accuracy(RMS)
Position	0.02 m
Roll	0.05 deg.
Pitch	0.05 deg.
Azimuth	0.1 deg.

The experiments were executed at the intersection of the Software Avenue Subway Station of Nanjing City, which is a metropolitan city in East China and over 8 million population. This intersection is a typical special intersection which is covered by vegetation in its central region. Fig.7 shows the trajectory of the probe vehicle at this intersection under two traffic situations (right-turn, go-straight).

B. Road modeling

Firstly, we can obtain some basic attributes of this intersection, such as the coordinates of the center point of this intersection $O=\left(31.978^{\circ}N,118.769^{\circ}E\right)$, the radius of the vegetation area in the middle of this intersection $b=60$ m and the maximum radius of this intersection $b_{\max} = 75$ m. In addition, there are 24 actual lanes which are connected to this intersection.

Secondly, we use the gradual optimization algorithm mentioned above to determine reasonable control points and optimal tension parameters for the cardinal spline at this intersection under two traffic situations. Reasonable control points for the cardinal spline can improve data storage efficiency of the model. Additionally, the value of the tension parameter for each individual cardinal spline segment will be gradually adjusted to satisfy a desired accuracy until the error between the roadway data points and the cardinal spline meets an acceptable range. Fig.8 shows the result of the cardinal spline road modeling-based on the gradual optimization algorithm under the right-turn situation. Fig.9 shows the result of the cardinal spline road modeling-based on the gradual optimization algorithm under the go-straight situation.

C. Performance evaluation of road modeling

As can be seen from Fig.8, there are five control points and four individual cardinal spline segment under the right-turn situation. The final optimal value of the tension parameter for these four individual cardinal spline are 1.1, 0.5, 0.4, 0.9 respectively. And the final right-turn virtual lane with cardinal spline fitting achieves the global accuracy of 1.05m by using five control points.

As can be seen from Fig.9, there are seven control points and six individual cardinal spline segment under the go-straight situation. The final optimal value of the tension parameter for these six individual cardinal spline are 1.1, 0.8, 0.4, 0.5, 0.9, 1.0 respectively. And the final go-straight virtual lane with cardinal spline fitting achieves the global accuracy of 1.24 m by using seven control points.

From the experimental results above, we can see that the cardinal spline road modeling-based on the gradual optimization algorithm uses a small number of control points to meet a desired lane-level accuracy under two traffic situations. Therefore, the lane-level intersection model proposed realizes a near-optimal balance between the accuracy and data storage of this intersection.

V. CONCLUSION AND FUTURE WORK

In this paper, we propose a novel lane-level road model for the special intersection which is covered by vegetation in its central region. The proposed intersection model is composed of two parts: topological structure and geometrical structure. Topological structure of this model can help describe the connectivity, turn restrictions and other attributes of the special intersection in the real world. The main contribution of this paper is to adopt the cardinal spline road modeling-based on the gradual optimization algorithm to represent geometrical structure of the special intersection, which can better approximates the real vehicle trajectory at the intersection. The gradual optimization algorithm can determine reasonable control points and optimal tension parameters of the cardinal spline for different traffic situations at the special intersection. In the future, more situations such as U-turn will be considered. In addition, more experiments will be conducted to further verify the effectiveness and reliability of this intersection model.

ACKNOWLEDGMENT

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