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Expression of moving object group movement in large scale traffic network[1]

Yan Zhengshu[2]

Abstract. In order to express the traffic scenes composed of crisscross road networks, large scale moving objects (such as the moving object) and their movement, a kind of expression technology is proposed for the movement of moving object group in large scale traffic network. First, a kind of hierarchical road network logic model was designed. According to the input vector data of road network lane line, the intricate traffic road network was described from geometry, topology and other hierarchies by logic modeling. Then, the lower computational efficiency of moving object group movement based on the microscopic method of individuals in the existing moving object group movement expression method, and the complex traffic phenomena cannot be expressed through the method based on small scale flow. Thus, a group of novel small scale flow equation was proposed to describe the movement of the moving objects in road network, which can offer an organic combination with the small scale flow model and the model of lane changing behavior of moving objects, as well as describe various complex traffic phenomena realistically. The experimental results show that, on the premise of achieving simulation in detail about moving object movement in large scale traffic network, the computational efficiency of the method in this paper has the same order of magnitudes with the general small scale flow model. In practical application, the virtual reality model of the real traffic road network was built, and the movement of moving object group was expressed on it. So the validity of this method was further verified.

Key words. Moving object group, large scale traffic network, hierarchical logic model, lane changing behavior of moving objects, small scale flow model, virtual reality.

1. Introduction

Transportation is one of the four aspects involved in human daily life of 'clothes, food, shelter and travel'. It is a significant component of human society. In order to exhibit the reality world in the spanning space of the computer, the traffic road network was constructed in virtual environment and the moving object and its

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[2]Information School, Ningbo City College of Vocational Technology, Zhejiang, 315100, China

movement in road network was expressed. Both of them are the essential steps in constructing virtual world [1–3].

The moving object movement in reality life has the following outstanding features: first, the structures of traffic road networks are complicated. All kinds of level crossings and various overpass routes are crisscross and intricate. Then the scale of the moving objects is huge. Therefore, how to realize the authentic simulation of moving object group movement in large scale traffic network is the significant problem in virtual reality. It is an effective technological method in the design, analysis and assessment of emergency evacuation plans and urban traffic projects as well. Its meaning and application prospects can be concluded in the following aspects:

1) Realize the rehearsing traffic simulation, and reinforce the ability to deal with special circumstances and emergencies (such as the large numbers of people evacuation in the Fukushima nuclear crisis).

2) Guide the design, assessment, programming of the traffic and so on.

3) Users experience in the enhanced virtual scene.

With the rapid development of virtual reality technology, the conceptions of virtual city, virtual tourism and others are widely proposed, integrating the distinct traffic simulation into them, which can further deepen the users' immersive feeling. The small scale simulation method is based on the model of fluid. The changing of traffic movement in the road is simulated from the small scale aspect like density and velocity [4–6]. The computation time of simulation has no relationship with the number of moving objects, which is mainly used in the simulation expression of moving object group movement. The TRANSYT system exploited by TRL in Britain and KRONOS software system exploited by University of Minnesota in America are using this kind of method. As a tool of traffic evaluation, programming and design, these system mainly study the roughly movement trend of the traffic flow. In order to enhance the computational efficiency, the model simplifies or even overleaps the simulation of individual moving objects movement behavior. It is unable to realistically describe the movement behavior of moving objects in various intricacy traffic scenes (such as various road changing behaviors), thereby reduces the veracity and authenticity of the simulation results.

In addition, the road network is the carrier of traffic flow, as well as the considerable basis data in traffic expression. The road network data in traffic expression is the mathematical abstract and standardized description of reality road network. Thus the road network which can be identified by computer is constructed. The road network data are usually required to describe the geometry information and logic information of the road network. In the expression computation of moving object group movement, the mentioned method also need to take road network data for basis. However, the present method has higher requirement for the input road network. It can first be reflected from larger amounts of input data quantity, for instance, in the plane intersections, the traffic phase is required to import or manually set to realize the detachment of conflicts routes. It has large amounts of workload and easy to generate mistakes. Then, when the model is applied to the expression of moving object group movement, the solution process of the position coordinate and direction angle of moving objects needs to seek the road network data and process approximation calculation of numerical values. It costs lots of time and influences the efficiency of large scale expression computational.

To solve the mentioned problem, we proposed a kind of method to express the moving object group movement in large scale traffic network. First, aiming at the road network data and its modeling, we proposed a kind of road network hierarchy logic model. We conducted topology generation and hierarchy logic organization for the imported lane line geometry data, and described intricate traffic road network from different hierarchies. Then, we proposed a group of novel small scale flow equation to describe the movement of moving objects in the road network, in accordance wit the movement expression computation of moving object group. This can offer an organic combination with the lane changing behavior of moving objects model, as well as obtain the movement condition of moving objects by optimized solution.

2. Related work

According to the degrees of the described details, the modeling of moving objects movement can be mainly divided into microscopic model and small scale model. The microscopic model describes the movement behavior and reaction of moving objects from individual moving objects. Car-following model and cellular automaton model are the two kinds of common used microscopic models. In the car-following model, according to the condition of the front car in current lane, its acceleration limit as well as the road curvature, the driver can ensure the accelerated and deceleration speed of the moving objects [7]. The basic thought of cellular automaton model is to disperse all the continuous variables [8]. The microscopic model can describe the individual behavior of moving objects in detail and combine with the model of lane changing behavior of moving objects. In this model, we can get a better traffic expression simulation result to show various complex traffic phenomena, traffic accidents, such as the road congestion, the intersection of lots of vehicle flows and so on. However, the computational efficiency of microscopic model has relationship with the scale of moving objects. Facing with the moving object group expression in large scale traffic network, its computational efficiency is relatively low.

The small scale model are usually called continuous flow model. This kind of model is mainly used in the traffic simulation and analysis of moving object group. Now, there have been a lot of classical small scale flow models. The anisotropy model adopts a mass conservation equation and accelerating equation to describe the traffic flow dynamics [9, 4]. The dispersed LWR equation is used to describe the traffic flow in the cell transmission model [10]. The other classical traffic flow model is grid flow model. Being is by optimal velocity model, Nagatani first proposed the grid dynamics model based on traffic flow [11]. The driver can react according to the local density ahead of the current lane. The movement of moving objects was calculated as the entire kinetic fluid. If these models are applied to the movement expression of moving object group, we are unable to know the detail information like whether the moving objects can change road or not and how to change road. Their precision is limited and they cannot express various traffic accidents.

Though the microscopic model can describe the movement behaviors of moving objects in detail, its computational efficiency is relatively low [6]. The small scale model can be used in the simulation of moving object group movement. However, the simulation accuracy is too rough, and the veracity and the visualization effect of the simulation results are limited, especially the incapable of simulating the various complex traffic phenomena and traffic accidents. Therefore, the modeling and expression of the moving objects movement in large scale traffic network are facing huge challenge.

3. The logic model of the moving object group movement expressions

Now most of the traffic simulation software used the microscopic model based on individuals to express the movement behavior of moving objects. This kind of model has low computational efficiency, which is hard to be applied in the movement expression of moving object group. The small scale method based on sequence flow is used to simulate the entire movement trend of the traffic flow from the aspects of entire vehicle flow. This method is very suit for the expression of moving object group movement in large scale road network. However, the present small scale flow model is limited in the rough scale to simulate the movement behavior of moving objects. It excessively simplifies the movement details of moving objects, especially ignores the road change behavior and process of the moving objects, which cannot realistically exhibit all kinds of complex traffic phenomena. In this letter, we modified the classical small scale flow model - co-pilot grid flow model [5]. A group of novel small scale flow equation was proposed to conveniently couple with and solve the lane changing behavior of moving objects.

3.1. The road network logic model

As mentioned above, considering the concrete problems in expression such as path programming, coordinate setting, movement smoothness and conflict avoidance, the expression of moving object group movement has higher requirement to the road network information. However, these methods have inadequate information, or the lower inquiring and computational efficiency. Therefore, we proposed the road network hierarchies logic model shown as the figure. From bottom to top, the model can be divided into lane layer, road segment layer and the path layer. The lane layer, only the axle wire Lane in lane is included, is the basis for the entire road network logic model. The road segment layer and the path layer describe the logic relationship of road network element Lane, including the section Link based on the definition of Lane, the Segment based on the definition of Link sets, the Connector represents the connection in sections, the Intersection represents the topology connection in sections and the Road represents the location dependent relationship.

The lane layer means the generalized lane line definition in this paper-Lane. In order to describe the moving orbit of moving objects, the Lane not only includes the lane axle wire with reality meaning, but also includes the curve describing the travel orbit of moving objects in the crossing, which is called virtual Lane (as shown in Fig. 1). The vector data information of Lane can be described with P. Here, P is the directed polyline constituted by point range, and meets the requirement if certain 'smoothness'. The nature of broken line has no smoothness. The smoothness means that the point ranges of this broken line should approach to the smooth curve fitted by point range as much as possible. Then, except for the crossing area, the average distance has the consistent Lane trend in threshold values and the roughly equal length. Finally, the out-degree and in-degree of all the inner nodes, respectively, are equal to 1.

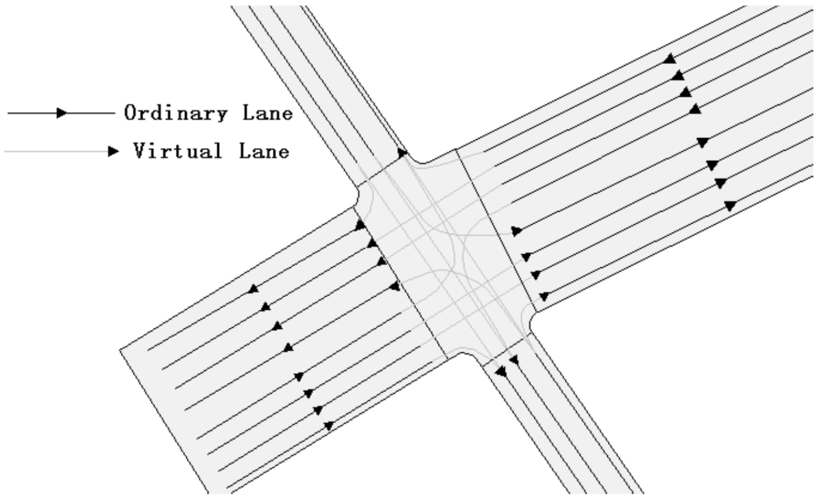

Fig. 1. Schematic diagram of Lane

Based on the mentioned logic description, the road network model can not only describe any complicated road network structures, including plane intersection and interchange, but also realize the phase distribution at the intersection by the same Intersection relates to the intersection of Lane information automatic. Thus, it can realize the automatic conflict separation of lines with different direction. All the logical information in the model can be automatically generated by the topological analysis of the Lane data, and the specific generating process is shown in Fig. 2.

3.2. The small scale flow model

In the movement process of the moving object, the driver can not only get the density and velocity information of the current lane, but also obtain the density velocity information of the left and right side of the lane. Based on this, this paper

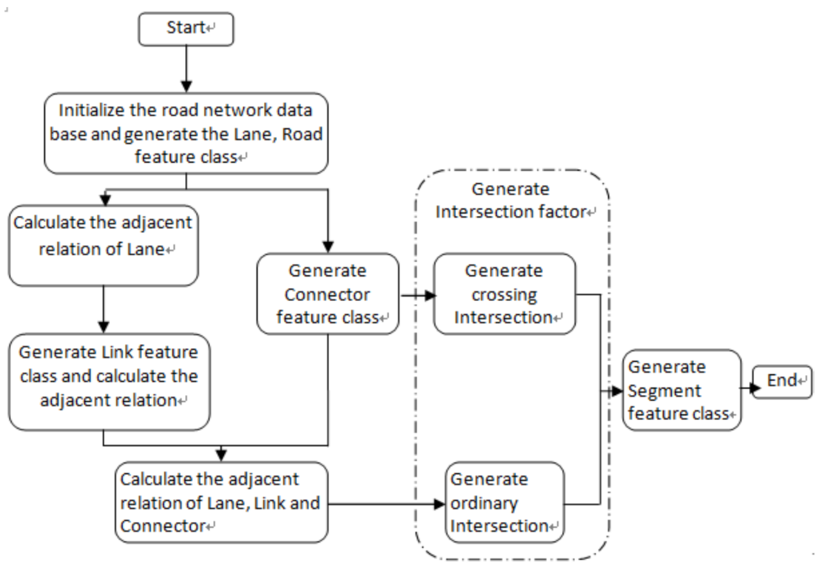

Fig. 2. Road network logic data generated flow chart

builds the following interactive cooperative driving grid flow model:

$$\begin{cases} \partial_t \rho + \nabla(\rho v) = 0, \\ \rho_{i,j}(t+\Delta t)\, v_{i,j}(t+\Delta t) = \\ \rho_0 \sum_{m=0}^{2} \left[f_{2-m}\left(H_{i,j}(t)\right) V\left(\rho_{i+1,j-1+m}(t), \ldots, \rho_{i+N,j-1+m}(t), \rho_j^*\right)\right]. \end{cases}$$

The difference between the above equations and the classical co-pilot grid flow model equation [5] is that the interaction term is added.

$$\sum_{m=0}^{2} \left[f_{2-m}\left(H_{i,j}(t)\right) V\left(\rho_{i+1,j-1+m}(t), \ldots \rho_{i+N,j-1+m}(t), \rho_j^*\right)\right]$$

.

This equation is used to describe the effects of the moving object in current lane, or in front of the adjacent lanes on the moving object in current position. Here, (i,j) represents the (i,j) grid directed along and perpendicular to the lane.

Here,

$$f_0(*) = \left\lfloor \frac{*+1}{2} \right\rfloor, \quad f_1(*) = ||*|-1|, \quad f_2(*) = \left\lfloor \frac{|*-1|}{2} \right\rfloor,$$

ρ_j^* means the car density in the (i,j) position in the current lane and the balanced place. $H_{i,j}(t)$is the direction of the car flow. When the car flow is directed to the left lane, $H_{i,j}(t) = -1$. When the car flow is directed to the right lane, $H_{i,j}(t) = 1$.

In other circumstance, $H_{i,j}(t) = 0$.

By using the finite difference method, the mentioned differential difference equations are fully discretized and the numerical stability analysis is performed. The equation has the only stable solution as long as determines$H_{i,j}(t)$. With the application of the behavior model, it is possible to determine whether the lane changing is feasible, so as to determine $H_{i,j}(t)$, and solve the movement state of the moving object.

4. Experimental results

Based on the mentioned method, we perform a moving object group movement expression system for large scale traffic networks, and carry out the practical application and validity test for the method in the urban road network. The efficiency experiment in this article is implemented on a workstation configured as follows: Core 8 Xeon (R) E31240 3.4 GHz CPU, 4.0 GBRAM.

4.1. Results and analysis of hierarchical road network model

First, the road network model proposed in this paper is compared with Wilkie's road network model [2] from the view of logic generation. Table 1 exhibits the comparison of the automation degree generated by logical data. It shows that the Wilkie's model requires additional manual interaction input for the intersection data, and needs to further install the traffic phase distribution for the conflict traffic routes as well, which possesses heavy workload and is prone to generate errors. The required input data in this model is just lane line data. Other data, including intersection data and traffic phase data describing the conflict relationship, can be generated automatically, reducing the input of two kinds of data. This not only reduces the workload of manual input data, but also avoids the introduction of artificial errors. In addition, the definition of intersections in this paper is not directed to specific intersections, instead, an Intersection is automatically generated according to the connecting and intersecting topologies. Therefore, any complex intersection models generated by the model can compare with the existing model, which has remarkable advantages in the data generated automation degree.

Table 1. Comparison of automation degree generated by logical data

	Intersection	Adjacency relationship	Connection relationship	Conflict relationship
Wilkie method	Manually interactively generated	Automatically generated	Automatically generated	Manually interactively generated
Suggested method	Automatically generated	Automatically generated	Automatically generated	Automatically generated

Second, the results of road network logical data automatic modeling and efficiency test are represented. The radius of 5 km of a city urban road, with a total of about 8,000 lanes was processed with the road network logic modeling. The logical modeling is based on the input Lane data. The results show that all the actual adjacent and connected lanes in this area are completely correct in this logical data. All the intersections, including all kinds of intersections, ring road junctions, various three-dimensional intersections and other conflict lines are also automatically generated by the intersection of the traffic phase to achieve the separation of the conflict, which proves the validity of the logical model of road network. Fig. 3 (left) and Fig. 3 (right) separately show the vector data of road network local roadway and road network local hierarchical relationship. The hierarchical relationship data in the schematic diagram uses different colors distinguish the different Links. The blue polygons mean the terminal information of Lane involved in the Intersections.

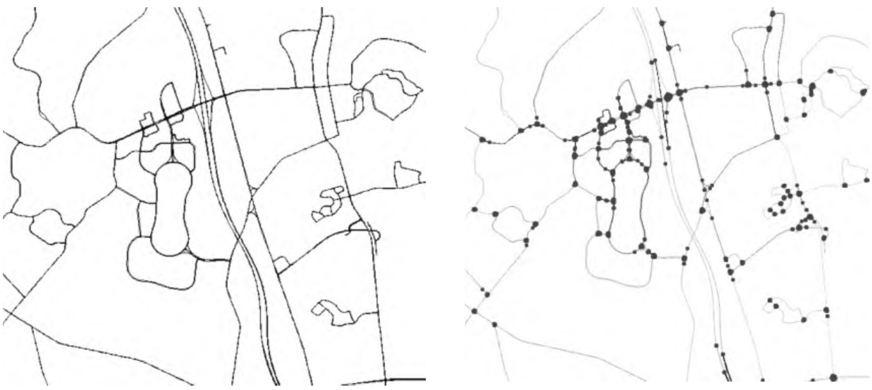

Fig. 3. Logical modeling results for a real regional road network

4.2. Result and analysis of movement expression of moving object group

The calculation efficiency and effects of moving objects in real-time expression were tested with the mentioned method. In the given road network scale, the computational efficiency of the system is almost irrelevant to the number of moving objects (Fig. 4), and has the same order of magnitudes with the classical small-scale flow model [5] (one-dimensional co-driver grid flow model). It shows that the proposed method can be used for moving object group movement representation. On the machine with the mentioned configurations, this method can express the movement of moving objects in the road network scale with total mileage of 600 km. The scale of the road network in this experiment is as follows: the total length of the lane line is about 600 km, and the uneven road segment accounts for about 20% of the total road network. Red line refers to the classical co-driver grid flow model [5] simulation results.

To further verify the effectiveness of the method, we selected traffic lane changing behavior of instance data with this method of moving objects occur frequently

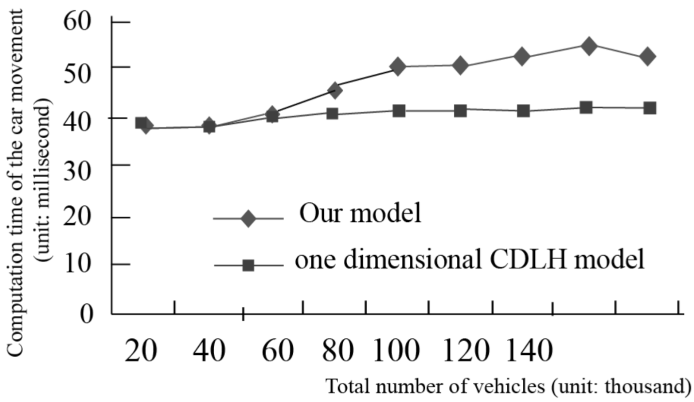

Fig. 4. Relationship between the number of moving objects and the expressed computation time

compared. We compared it with the traffic instance data which were published on the Next Generation Simulation (NGSIM) website. NGSIM was a kind of website initiated by the Federal Highway Administration of Transportation (FHWA). We used an up-ramp segment on the Interstate 80 road of the city of San Francisco on the site (as shown by the two thick straight-line markings in Fig. 5). We track all lane change objects within 1 minute of the road segment. The section of the highway is on the ramp section, moving objects from the ramp into the main road after the frequent lane change behavior.

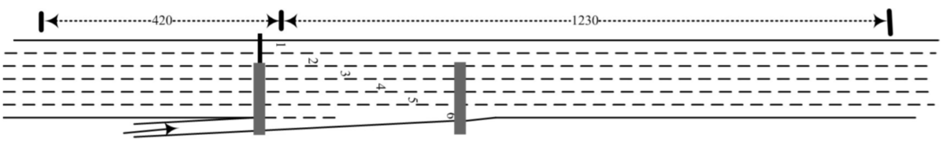

Fig. 5. Road conditions of instance data acquisition area

The measured data in the section of the period of time occurred in a total of 12 lane behavior. A car from a lane through the lateral movement (perpendicular to the lane direction) into the adjacent lane is called once lane change behavior. The start time of the lane in the measured data is the time when the moving object starts to shift sideways to the target lane. The end time is the time when the lane of the lane reaches the target lane and the moving object is oriented in parallel to the lane direction. The duration of the lane is the difference between the lane end time and the lane change start time.

Next, we compare the duration of the lane simulation and the length of lane change in the measured data. Fig. 6 represents the comparison diagram of the actual time length and the analog time length for 12 times of lane change behaviors in the comparison period. It shows that in the vast majority of lane changes, the model simulation results and the measured data have roughly equivalent lane length. Further analysis shows that the average error of the lane length and the measured results is about 1.1 s.

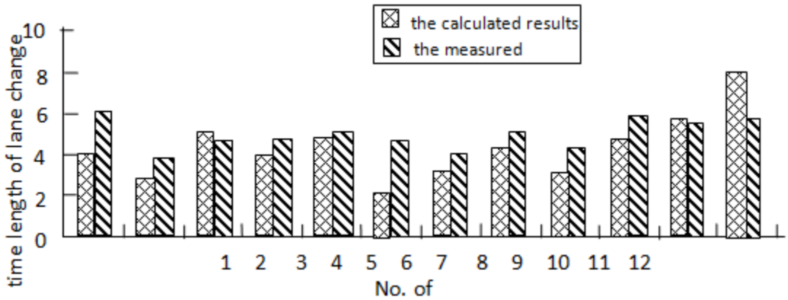

Fig. 6. Comparison of the duration for lane change

5. Conclusion

With the development of virtual reality technology, the research of virtual city has been greatly developed. The high-detail, high-fidelity mobile object motion simulation technology has integrated into the city simulation. It plays an important role in improving the reliability of simulation and enhancing the visual experience, as well as traffic design and traffic planning. The existing moving object motion simulation method can not only describe the general trend of traffic flow and cannot simulate the interaction behavior of moving objects between lanes, but also simulate the movement of urban moving objects, which reduces the realism and credibility of the simulation results. In this paper, a method is proposed for motion representation of moving objects within a large scale transportation network. And the technical details of the method are expounded from the aspects of road network logic modeling, moving object group motion expression calculation and so on. The experimental results and application examples show that this method has the following significant advantages: First of all, the method of road network data input requirements are low, only need to enter the lane line vector data to meet the needs of animation expression; secondly, the efficiency of the real - time simulation method is almost independent of the number of moving objects, making the method applied to the simulation of moving object group motion; finally, the method can be described in detail when moving objects and how to change lanes and other acts, which improves the simulation of fidelity and accuracy.

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