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The Road Regional Hazard Level Evaluation Method Based on Ising Model

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Abstract— **On-road risk assessment is one of the important topics for intelligent vehicles research. Efficiency of risk assessment is affected by lack of on-road vehicles information, which should be solved by The Vehicular Ad-Hoc Network (VANET). In this paper, a regional vehicles hazard level estimation method, which employs Ising model to explain the inter-vehicles relationship, is proposed, an inter-vehicles relationship model is constructed, and corresponding parameters mapping relationship is studied. Then Ising model's energy formula is used to illustrate regional hazard level. Moreover, based on the inter-vehicles relationship, we present an approach to build a regional threat distribution map, which indicates the passing threat of a certain ego-car. A series of experiments are done to examine the efficiency of the proposed method. Experiment results show that the proposed method can produce a reasonable danger evaluation for an ego-car.**

I. INTRODUCTION

Risk avoidance is one of the major hot points that should be considered in Advanced Driver Assistance Systems (ADAS) and Autonomous Driving (AD) functions design. Due to the complex road environment, it is unfeasible to evaluate all possible state evolution alternatives of the involved traffic participants [1].

In actual fact, road drivers take great care of driving risks, and care little about the cause of risk. Hence a road risk distribution map is useful to decision makers in ADAS/AD system [2]. Spatial occupancy grids are used for constraining the drivable space to risk-free areas [3].

Road risk distribution is decided by a series of physical factors related to the driving contexts, such as road condition, traffic density, regional average speed, surrounding traffic participants' characteristics, etc. Julian Eggert [4] believes a microscopic risk model, which could estimate the possibility that a dangerous event for example an accident could happen within a future time interval, is useful for driving trajectory schedule, and then discuss the mapping between the microscopic risk model and the accident statistics. In [3], a vehicle passing scenario is employed to illustrate future collision event probability and survival function for the case of multiple risks. However, vehicle-passing scenario presented in [3] only considers single passing vehicle row. In a real situation, instead of single vehicle row, an ego-car should try to pass vehicle group in object region, which includes multi-row and multi-column vehicles. Hence, both joint threat of regional vehicles and regional threat distribution function should be considered in risk estimation progress. To track this problem, three key points - object region division, regional hazard level estimation, and regional threat distribution map generation - should be taken into account.

Without VANET, it is hard to get on-road vehicles' real-time information, and thus it is difficult to build a real-time road risk distribution map. With development of inter-vehicle communications (IVC) system, most recent approaches for active safety take on-road vehicle status into consideration. Therefore, real-time hazard evaluation for regional vehicle group becomes a highly valuable research directions in ADAS /AD [5].

In our previous work [6], a large-vehicle-first road section hazard level estimation method, which employs a gravity model to illustrate inter-vehicle relationship, is proposed. However, this method did not consider vehicles moving tendency. Regional hazard level estimation method based on simple weight accumulation is too simple to explain the complicated character of object road region. In [7], Ising model, a classical physical model, is used to explain inter-vehicle relationship. Although [7] just used single-lane closed-ring scenario, which has discrepancy with actual road condition, for performance simulation process, it unlocks a new thought to explain inter-vehicle relationship. Magnetic energy employed by Ising model provides a method to illustrate group energy. This model could be used to explain regional hazard level and support regional threat distribution map generation.

Therefore, in this paper, combining regional hazard level estimation method of [6], which base on large-vehicle-first cluster, with Ising model, a new road regional hazard level estimation method is proposed, This method bases on the relationship between every two cars in the road area and takes into account the role of all vehicles and is therefore more comprehensive, and a regional threat distribution map is built according to inter-vehicle relationship. Moreover, passing threat of ego-car is estimated according to adjacent grid energy.

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In order to verify the validity, experiments based on Anylogic 6.0(Section IV.A) are done. Before commercialization of VANET, it is difficult to get accurate on-road vehicle information. Then radar and sensor detection data set of Haier road, Chongqing, China, is used as substitution to simulate real-time on-road vehicle distribution.

The rest of the paper is organized as follows. Section II provides present construction process of inter-vehicle relationship function. In Section III, the regional energy calculation method is given, while experiment results and corresponding analysis are presented in Section IV. Finally, the conclusion and future work are given in Section V.

II. INTER-VEHICLE RELATIONSHIP

Regional vehicle hazard level is determined by two factors. One is all intra-region vehicles' status, which is defined as vehicle health level [8], and the other is pair relative location relationship of intra-region vehicles. Then we can define inter-vehicle relationship as

$$R(i,j) = f\left[C_{HV}(i), C_{HV}(j), d_{ij}, \rho, \Delta v_{ij}\right] \tag{1}$$

where $C_{HV}(i)$ and $C_{HV}(j)$ represent health level of vehicle i and j respectively, which is obtained by the method of [8], ρ is vehicle density of object region, Δv_{ij} is the speed difference between vehicle i and j, d_{ij} is distance between vehicle i and j.

There is thus a need for a model to explain inter-vehicle relationship. In this paper, Ising model, a classical physical model, is investigated to construct a corresponding model, and is described in details in this section.

A. A. Spin-spin correlation in Ising model

Ising model, is a mathematical model of ferromagnetism in statistical mechanics.

The model allows the identification of phase transitions, as a simplified model of reality. Ising model is one of the simplest statistical models to show a phase transition [9].

Ising model defines spin-spin correlation as

$$g(i,j) = \langle (s_i - \langle s_i \rangle)(s_i - \langle s_j \rangle) \rangle \tag{2}$$

where $\langle\rangle$ is the average magnetic moment of the spins, which is a constant that can be queried, s_i and s_j denote the status of spin i and j respectively.

Consider a set of lattice sites Λ, for any two adjacent sites $i,j \in \Lambda$ one has an interaction $J_{i,j}$. Also a site $j \in \Lambda$ has an external magnetic field h_j interacting with it. Moreover, for an infinite system, the average magnetization fluctuations are influenced by environment temperature. The higher the temperature is, the stronger the random fluctuation interference will be.

Similarly, inter-vehicle relationship is influenced by vehicle density, When the vehicle density exceeds the critical density of the vehicle, vehicles in corresponded large area of traffic jams stop. At this time, the vehicles will transmit and affect vehicles that are far apart and have a wide range of influence. At this time, the traffic situation in the entire road area has changed dramatically. So the vehicle density which could be used to replace temperature parameter of Ising model, while cruise direction and speed difference could be equivalent to external magnetic field. Hence, we believe that Ising model is useful in inter-vehicle relationship definition. Still, that leaves us with the main question. Does any barrier exist in employing Ising model to explain inter-vehicle relationship?

B. Limitations of spin-spin correlation

Ising model allows a site to be in one of only two states (i.e. q = 2). Regarding to traffic flow, the site can either be vacant, or be occupied by a vehicle. The structure of the Ising model makes it incapable of distinguishing vehicles of different species, such as large vehicles and small cars [10]. Moreover, the pair relative location relationship of spins is invariant. As a result, the Ising model cannot be used to analyze mixed traffic flows, which must be considered in on-road region hazard level evaluation. Hence, Ising model needs to be revised by adding vehicle parameters.

C. Inter-vehicle correlation function

To some degree, spin-spin correlation function can explain inter-vehicle relationship. However, Equ.(2) can not be used directly to denote inter-vehicle relationship due to health level differences among road vehicles. According to Referential vehicle classification rule of American Environmental Protection Agency EPA and GB9417-89 standard of China, we classify road vehicle's health level into ten grades (I to X). The higher health level is, the more dangerous the vehicle will be.

Here vehicle's health level is taken as spin status parameter. Ising model considers that small magnetic needles within a certain distance would interact via energy confinement and cause a change of state. Similarly, in a road environment, vehicles have different health states. Interactions between vehicles at a certain distance will occur and transitions between different states will be caused. Therefore the average magnetic of spin is corresponded to average health level of related grades (IX). Moreover, a weight factor, which considers regional vehicle density and dynamic position, should be introduced in inter-vehicle correlation function.

Hence, Equ.(2) is revised as follows,

$$J(i,j) = W(i,j) \langle (C_{HV}(i) - \langle C_{HV}(i) \rangle)(C_{HV}(j) - \langle C_{HV}(j) \rangle) \rangle \tag{3}$$

where $W(i,j)$ is weight factor and can be illustrated as

$$W(i,j) = \frac{\rho}{e^{d_{ij}/d_0}} \cdot \frac{1}{k^{\Delta v_{ij}}} \tag{4}$$

where d_0 is inter-vehicle minimum safe distance [6]. k is an attenuation coefficient, ρ is vehicle density of object region.Here we only considered the scenario that all vehicles cruise in same direction. In this case, the spin direction should be illustrated by the change of inter-vehicle distance and relatively velocity Δv_{ij}.

Taking account of vehicle's health level, inter-vehicle relationship could be illustrated as

$$R(i,j) = J(i,j) \cdot L_H(i) \cdot L_H(j) \tag{5}$$

III. Hazard Level Of Road Region Vehicles

Regional vehicles' joint hazard level estimation is a key step in road risk assessment procedure. Hazard level of front road region greatly influences the decision making of ADAS /AD control system. In this paper, we focus on the construction method for joint contribution function. Ising model provides a group energy equation, which is regarded as a viable approach to denote group joint contribution, and is employed here to illustrate regional vehicles' joint hazard level.

A. Regional hazard level

Assume $s = (s_k)_{k \in \Lambda}$ is an assignment of spin value to each lattice site. As defined in Ising model, for any two adjacent sites $i, j \in \Lambda$ with an interaction $J_{i,j}$, the energy of a configuration s is given by the Hamiltonian function,

$$H(s) = -\sum_{(i,j)} J_{i,j} s_i s_j - B \sum_j s_j \tag{6}$$

where B represents an external field that is acting on the entire system.

Here we use V , average vehicle speed in object region, as substitution of B . Then regional hazard level should be denoted as,

$$E\{r\} = -\sum_{(i,j)\in region} J_{i,j} L_H(i) L_H(j) - V \sum_j L_H(j) \tag{7}$$

E{r} is used in risk assessment. It provides decision criteria for ADAS /AD control system, and then suggest vehicle further event, such as following or passing front vehicle group.

B. Regional threat distribution

When a vehicle decides to pass front vehicle group, it definitely wants to find a relatively low risk trajectory, which should be planned according to regional threat distribution map. In this paper, based on inter-vehicle relationship, we present a threat distribution map construction method and steps are as follows;

- **Step 1**: Calculate inter-vehicle relation energy of vehicle i as

$$E\{i\} = \sum_{j=1}^{n} R(i,j) \tag{8}$$

  Where n is the vehicle number in object region;
- **Step 2**: Calculate radiant energy of E{i} on each grid.

$$E(i, grid) = \sum_{i=1}^{n} \frac{E\{i\}}{L_i^2} \tag{9}$$

  where L_i is the distance between vehicle i and object grid center (Centre of vehicle position in simulation).
- **Step 3**:Calculate energy of each grid.

$$E(grid) = \sum_{i=1}^{n} E(i, grid) \tag{10}$$

C. Passing threat

In the following, we will concentrate on the most important context information for collision accident: the spatial proximity between traffic participants.

As mentioned above, we can calculate energy of each grid and obtain regional threat distribution map. Hence, the passing threat of ego-car should be illustrated by the radiation energy of ego-car-dependent grids. Assuming the number of ego-car-dependent grids is g , passing threat of ego-car is defined as

$$Threat(p_{ego}) = \sum_{i=1}^{g} E_{grid}(i) / d_{ego,grid}(i) \tag{11}$$

where p_{ego} is ego-car's position and $d_{ego,grid}$ denotes the spatial distance between ego-car and object grid center.

IV. Experimental Results And Analysis

A. Simulation platform

In this paper, an agent-based modeling simulation platform called AnyLogic is employed to fully analyze the proposed procedure. AnyLogic includes a graphical modeling language and allows the user to extend simulation models with Java code. Based on AnyLogic 6.0 platform, a formal specification framework is coupled with an agent-based model for the modeling and simulation of road vehicle in any complex environment. Moreover, MATLAB is employed to draw threat distribution map.

B. Experiment parameter setting

The velocity radar and camera detection data of Haier road, a high-density large vehicles area in Chongqing, is used to simulate real-time road traffic condition. On Haier road, the velocity radars are installed every 50 meters, while cameras are placed every 100 meters. All collected data are gathered by transportation administrator office of Chongqing, who supports this research greatly. To simplify simulation process, here we only consider two kinds of vehicles, which are heavy-duty trucks and passenger cars. The initial health value is assumed obeying normal distribution.

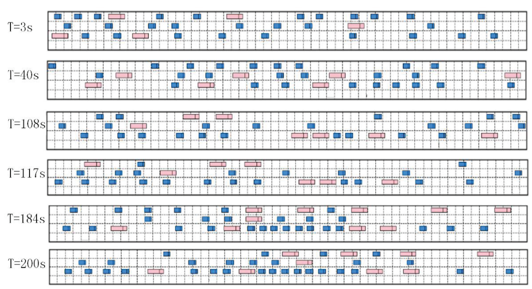
Other experiment parameters settings are given in TABLE I.

C. Experiment results and analysis

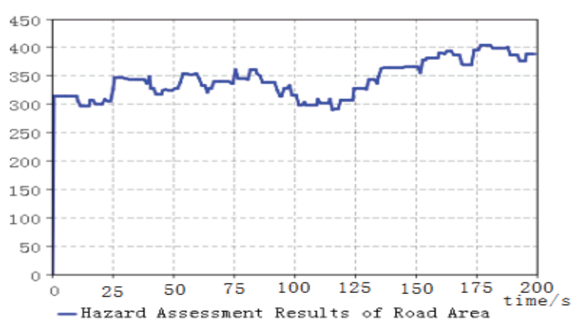
1) **Experiment 1**
   Experiment 1 is done by AnyLogic 6.0 platform to illustrate the performance of regional hazard level estimation method.
   Experiment results are shown in Fig.1.

TABLE I
DEFAULT VALUES OF THE PARAMETERS

Definition	Value
The length of road section	240m
The number of lanes	4
The width of lane	4m
The danger level of vehicle	I to X
The length of large vehicle	8m
The length of ordinary vehicle	3.5m
The vehicle's maximum velocity	60km/h
The vehicle's minimum velocity	5km/h
The maximum velocity when the vehicle change lane	25km/h



(a) Vehicle distribution map according to radar and sensor detection data of Haier road



(b) Regional hazard level

Fig. 1. Regional hazard level estimation

As shown in Fig. 1(b), regional hazard level constantly changes over time, ranging from 270 to 410. The peak value occurs at t=184s, when the region experiences high vehicle density and high large vehicle density. Furthermore, the valley, which occurs at t=117s, corresponds to a relatively low vehicle density.

We believe the estimation results are useful for driving decision-making. The key problem for next step research is the decision threshold selection. That is how to find a reasonable threshold to make decision, such as following, joining or passing. The threshold selection shall be done based on risk statistical analysis.

2) **Experiment 2**

Experiment 2 is done by MATLAB tool to obtain regional threat distribution map.

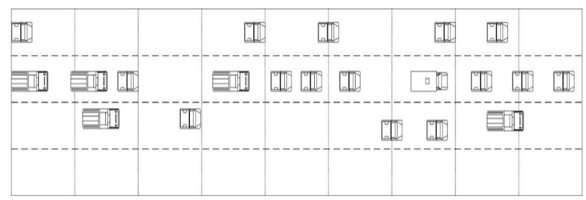
As mentioned above, according to Equ.(10), we can calculate grid energy at any time t.

Here we employ radar detection data of Haier road to simulate. The detail of corresponding data is listed in Table II.

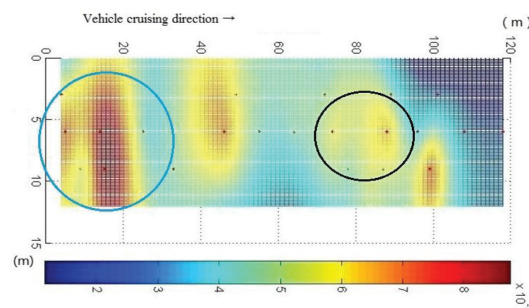
TABLE II
THE SIMULATION TIME

	Time	Large vehicle number	Small car number
T	17:30 16/12/2016	5	15
T+1min	17:31 16/12/2016	6	13

Experiment results of time t are shown in Fig.2.



(a) On-road vehicle distribution



(b) Threat distribution map

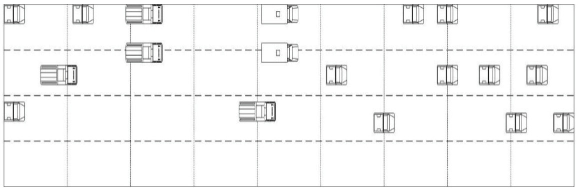
Fig. 2. Experiment results of time T

As shown in Fig.2, we can easily find the high threat grids, which include large vehicles. For example, the high-energy area in blue ellipse, including three large vehicles and covering all three lanes, will bring potential dangerous to surrounding vehicles. Under this condition, the wise choice for ego-car is to follow them. In addition, although the high energy in black ellipse covers a relatively large area, the energy level is low. In this case, to sped and pass may be an appropriate choice.

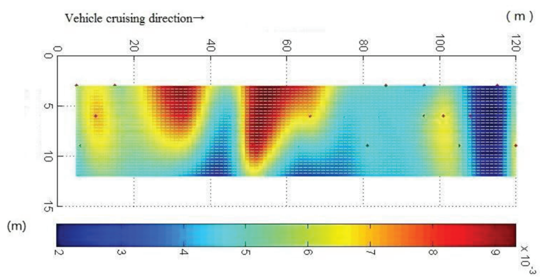
Experiment results of time $\mathrm{T+1min}$ are shown in Fig.3.

As shown in Fig.3, one minute later, a higher energy area appears due to an overtake event of one large vehicle. In Fig.3(a), a scenario of three vehicles going abreast is observed. And we can infer that the following decision of time T is reasonable.

All above experiment results show that the proposed method could illustrate road hazard status effectively and feasibly.



(a) On-road vehicle distribution



(b) Threat distribution map

Fig. 3. Experiment results of time $\mathrm{T}+1\mathrm{min}$

3) **Experiment 3**
Experiment 3 is done to illustrate passing threat of ego-car. The ego-car experiment aims to investigate the impact of other lanes vehicles on ego-car. Hence, we assume no forward vehicles and no following vehicles in ego-car lane.
Here we set g=15 . As illustrate in Fig.4, we assume ego-car locate on the yellow grid, and then the energy of all purple grids shall be considered to calculate passing threat.

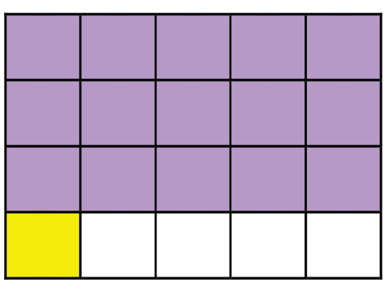


Fig. 4. Girds for energy calculation.

Based on Equ.(11), we can calculate radiation energy in selected grids and obtain passing threat of ego-car. Experiment results are shown in Fig.5.
As shown in Fig. 6, grid energy radiation could reflect passing threat.
At time t_1=2s, ego-car is adjacent to a large vehicle, while the vehicle density of surrounding area is relatively low. Hence, the passing threat, which equals to 8, is near intermediate value.
At time t_2=15s, ego-car is adjacent to a small vehicle, while the vehicle density of surrounding area is also low. The passing threat equals to 6, which is lower than that of t_1.
At time t_3=38s, a peak value occurs, which relates to two adjacent large vehicle and high local vehicle density.
At time t_4=42s, we can observe a valley point, which is caused by a low vehicle density and no adjacent large vehicle.

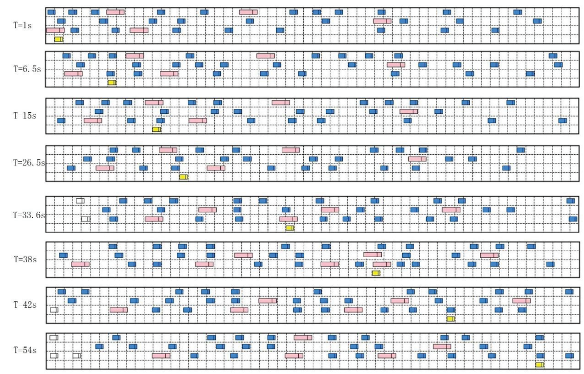


Fig. 5. Vehicle distribution map when the ego-car passes.

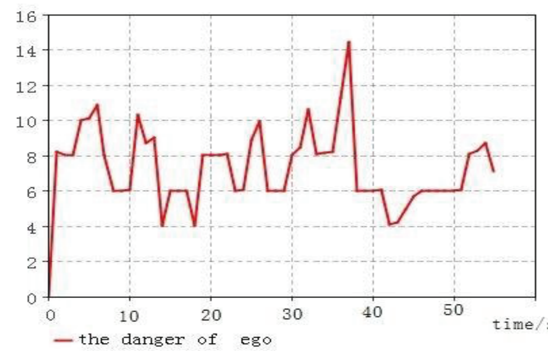


Fig. 6. Passing threat of ego-car.

V. Conclusions And Further Research Direction

An efficient risk assessment method is helpful to improve road safety performance. The real-time traffic evaluation problem largely affects the efficiency of assessment results and leads to a slow progress of real-time hazard level estimation.

In this paper, Ising model is introduced to explain inter-vehicle relationship and lays the foundation for real-time risk assessment. With regard to vehicle health level, regional vehicle density and relation position of vehicles, an inter-vehicle relationship function is constructed based on spin-spin correlation of Ising model. Furthermore, a combined energy parameter is used to illustrate regional hazard level, and the intra-region threat map is obtained through an energy superposition and attenuation process.

To display the effect of the proposed model, the AnyLogic 6.0 platform is employed as a formal specification framework, which is coupled with an agent-based model and used to simulate road vehicle status. Due to the limitations of the platform, the lateral speed, driver individual differences and related data collection, processing costs are not yet considered in the experiments we conducted. We will take these factors into account in the follow-up work.

Experiment results clearly show that we can track on-road energy changing, and hence can assess the road section's risk level. This proposed method is beneficial for road safety state warning and driving trajectory planning algorithm.

The presented model in this example employs radar and sensor data set, and may deviates from real road distribution status. It is therefore considered that future models will reflect upon the real road traffic data. Real road traffic data will also be used to guide the design of the environment model. Moreover, the risk assessment model should be considered in our future work.

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