Modeling and Simulation on Cooperative Movement of Vehicle Group Based on the Behavior of Fish

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Abstract. Fatigue driving might affect the traffic safety when the vehicles are on the cruising state in highway. Trying to solve this problem, this paper uses the movement pattern of the fish to the vehicles fleet, and develops a model of vehicle group with realistic restrictions based on the existed fish algorithms, the mobile behavioral model and cluster behavior model, and then demonstrates the feasibility of applying the fish behavior to the cooperative movement of vehicle groups through analyzing the trajectory, velocity and spacing of vehicles.

Keywords: Fish behavior · Internet of vehicle · Groups move · Vehicle cruise

1 Introduction

Vehicles stay a long-term cruise state on highway or urban expressway. Relative to the general road, the vehicles are in a simple status where there are no traffic lights and reverse traffic interferences. But in this situation, it is easy for driver to feel fatigue, which will affect the safety and comfort of driving. And fatigue is the major reason resulting traffic accidents. In this case, we urgently need an auxiliary driving system or automatic driving system which can replace the driver to operate in a relatively simple closed environment.

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Internet of Vehicles is a simply self-organizing network which is different from the ordinary. Because it uses the radio frequency to identify different Vehicles which equipped with electronic labels in the road, so that to achieve the extraction, supervisory and efficient use of state information from all vehicles in the net [1]. It implements the network interconnection between vehicles and travel environment by gathering a lot of basic information, such as the states of vehicles, road congestion and so on, and then communicates with other vehicles, thus make the travel of vehicles more secure, more convenient and more intelligent.

On the other hand, however, there is a certain defect in the existing communication technology, in spite of AODV showing better performance in average End-to-End delay and throughput under DSDD and SSDD techniques [2]. Moreover, the simulation results in [3] show that building and vehicle obstructions significantly attenuate the signal thus resulting in lower received signal strength, lower packet delivery ratio, and shorter effective transmission range, and the growth in the number of heterogeneous interconnected systems, as well as the emergence of new requirements in applications and services are progressively changing the original simplicity and transparency of the Internet architecture [4].

And the 5G network, which is proposed in recent years, can be a good solution to these problems [5]. And there are lots of works have studied in 5G network and vehicular network. For instance, in [6], Haijun Zhang present an overview of the challenges and requirements of the fronthaul technology in 5G LTE-U UDCSNets. In [7, 8], Shanzhi Chen present a potential step change for the evolution toward 5G, and propose long-term evolution (LTE)-V as a systematic and integrated V2X solution based on time-division LTE(TD-LTE). In [9], a delay-optimal virtualized radio resource scheduling scheme is proposed via stochastic learning. In [10–12], Chunxiao Jiang propose a credible information-sharing mechanism capable of ensuring that the vehicles do share genuine road traffic information (RTI), and study the outage probability of road traffic information sharing in underlay cognitive vehicular networks under both a general scenario and a specific highway scenario. In [13], a unified networking architecture is presented, starting from the inside of the vehicle and the interconnection of various control units and ultimately targeting Car-to-Car communications which enable smarter, safer and more efficient transportation.

In addition, the scientists get inspirations from some specific behavior of the biological community, such as Ant Colony Optimization (the ACO) and particle swarm Optimization (PSO), which are the most widely applied. And we will apply fish behavior into this paper.

So far, the Fish Principle has been widely used in Combinatorial optimization, grid planning, wireless coverage and other various fields [14, 15], and in the transportation field: Wang Jian and Ren Zihui proposed the application of artificial fish algorithm in vehicle behavior under serious traffic incident [16]; Scientists in Ministry of Transport Highway Science Research Institute, Jiang Shan put forward artificial fish school algorithm in the field of traffic distribution applications [17]; Lai Lei carried out the idea of applying the fish group model to the direction of multi-vehicle coordination driving control [18]; The core idea of Fish Principle is that the fish's behavior at the next time depends on the state and the environment mostly. At the same time, it will also affect the activities of the fish around it. We can easily think of the vehicle group from the fish group. The driving condition of every vehicle at next time depends on the condition of surrounding vehicles at this time and the road conditions, and its conditions at this time will also affect the activities chosen by the surrounding vehicles at next time [19]. Vehicles which cooperate with others just like the fish swimming in the highway.

Aim at the problems like long-time driving, low efficiency, and traffic accident, this paper put forward an improved model which based on the swarm intelligence, fish behavior and vehicle cruise state. We use the simulation software to analysis the trajectory, speed changes and separation distance between vehicles, then achieve the formation of team driving within the limits of road and avoid collisions. So as to improve the traffic efficiency, enhance driving comfort and make unmanned driving become true. Simultaneously, it is also benefit to driving safety and energy conservation.

2 Cooperative Model of Vehicle Group

There is a finite observable vehicle in the agreed two-dimensional road space, and each vehicle moves at its own speed. At the same time, each vehicle can exchange information, such as position, speed and acceleration, with other vehicles within a certain range in the surrounding area, we call this range R_0, and these vehicles neighborhood. Based on the current vehicle communication distance, the communication range of each vehicle is set to 300 m [20].

The target vehicle, which is randomly defined, is denoted as vehicle i. The position of vehicle i at time t is denoted as $P_i(t) = [x_i(t), y_i(t)]$. The neighbor of i is defined as

$$N_i(t) = \left\{j : \left[x_i(t) - x_j(t)\right]^2 + \left[y_i(t) - y_j(t)\right]^2 \leq R_0^2\right\} \tag{1}$$

And the number of neighbor is donated as $n_i(t)$.

At the same time, the speed of i and j at time t is denoted as $v_i(t)$ and $v_j(t)$, the acceleration of i and j is $a_i(t)$ and $a_j(t)$.

According to the analysis, the forces which are acting on vehicle i at time t can be described as

$$\mathrm{F} = F_1 + F_2 + F_3 + F_4 \tag{2}$$

In which, F_1 is mobile behavioral model, F_2 is the cluster behavior model, F_3 is the force from lane line. And they can be described as follow:

(1) Similar to the alignment principle of fish group mentioned in [21], each vehicle also tends to maintain a consistent orientation with its neighbor vehicle, that is, the moving direction of i at time t is the average acceleration of its neighborhood at time t − 1.

The moving direction of i is expressed as

$$a_i(t) = \frac{1}{n_i(t-1)} \sum_{j \in N_i(t-1)} a_j(t-1) \tag{3}$$

And F_1 is

$$F_1 = m_i a_i(t) \tag{4}$$

In which, m_i is the mass of vehicle i, and the value of m_i is 1 in simulation.

(2) Suppose that j $\in N_i(t)$ and j is front of i, the position of j is $P_j(t) = \left[x_j(t), y_j(t)\right]$.

The distance between i and j is

$$d_{ij}(t) = \left\| P_i(t) - P_j(t) \right\| = \sqrt{\left(x_i(t) - x_j(t)\right)^2 + \left(y_i(t) - y_j(t)\right)^2} \tag{5}$$

If the vehicle j brakes, j will slide forward for a while. The distance traveled by vehicle j during this time is denoted as $s_j(t)$, and $s_j(t)$ can be described as

$$s_j(t) = \frac{\left(v_j(t)\right)^2}{2\mu g} \tag{6}$$

In which, g is the gravitational acceleration, and μ is the friction coefficient between tire and road. In general, the friction coefficient of asphalt pavement is 0.4–0.8 [22]. In order to facilitate the calculation, and considering that the road may be put into use for many years, the friction coefficient is set as 0.5.

As we mentioned previously, the information of target vehicle i is known to its neighbor vehicles in the environment of IOV. If i receives the information that j is broken, i will also brake immediately.

Likewise, if i brakes

$$s_i(t) = v_i(t)(t_r + t_d) + \frac{\left(v_i(t)\right)^2}{2\mu g} \tag{7}$$

In which, t_r is the reaction time of machine, t_d is the delay time for information exchange of vehicles, $(t_r + t_d)$ is set to be (0.75 s + 0.054 s) [23, 24]. And during the time $(t_r + t_d)$, i is still running in the speed $v_i(t)$.

The distance difference of sliding forward between the two cars is donated as $s_{ij}(t)$, and

$$s_{ij}(t) = s_i(t) - s_j(t) = \frac{\left(v_i(t)\right)^2 - \left(v_j(t)\right)^2}{2\mu g} + v_i(t)(t_r + t_d) \tag{8}$$

According to the works in [25], we can know that the force between the vehicles is divided into repulsion force and attraction force. When the distance $d_{ij}(t)$ between i and j is further than $s_{ij}(t)$, F_2 is attraction force, recorded as $F_{attract}$. And the larger $d_{ij}(t)$ is, the greater $F_{attract}$ is. If vehicle i accelerate toward vehicle j, the distance between i and j becomes smaller, and thereby the transportation efficiency can be improved; when the distance $d_{ij}(t)$ between i and j is shorter than $s_{ij}(t)$, F_2 is repulsive force, recorded as $F_{exclude}$. In order to avoid collision, vehicle i slows down to maintain the distance with the vehicle j; when $d_{ij}(t)$ is equal to $s_{ij}(t)$, $F_2 = 0$ As shown in Fig. 1, the force between i and j exerted on vehicle i is expressed as an attractive force.

In order to ensure traffic efficiency, we compress the distance between the front and rear vehicles to a safe distance $s_{ij}(t)$. The traffic accidents generally occur between the front and rear vehicles on the highway, So in this paper, we give priority to the front and rear vehicles. That is, the range of the force of i applied to the surrounding vehicle is all set to be $s_{ij}(t)$

Here we introduce a negative exponential function to characterize the forces acting on the vehicle which is changing with the distance. So, the attraction force and repulsive force can be expressed as:

$$F_{attract} = m_i A_0 exp\left(-d_{ij}/s_{ij}(t)\right) \times \frac{p_j(t) - p_i(t)}{\left\|p_j(t) - p_i(t)\right\|} \tag{9}$$

$$F_{exclude} = m_i A_1 exp\left(-d_{ij}/s_{ij}(t)\right) \times \frac{p_i(t) - p_j(t)}{\left\|p_i(t) - p_j(t)\right\|} \tag{10}$$

Finally, F_2 can be expressed as

$$F_2 = \sum\nolimits_{j \in N_i(t)} F_{attract} + F_{exclude} \tag{11}$$

Where, A_0, A_1 are parameters of system. And after a number of tests, A_0, A_1 are set as 5,25 finally, and $\frac{p_j(t)-p_i(t)}{\|p_j(t)-p_i(t)\|}$, $\frac{p_i(t)-p_j(t)}{\|p_i(t)-p_j(t)\|}$ are the direction of force.

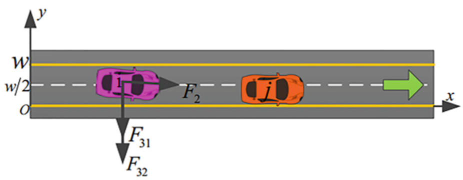


Fig. 1. The diagram of forces acting on the vehicle i

(3) In order to ensure that the vehicles are running within the limits of the lane, i will be subjected to the forces from both road sides. When i is in the position shown in Fig. 1, the vehicle will be repelled by the upper boundary, and attracted by the lower boundary at the same time. Similarly, the closer (farther) vehicle i approaches (gets away from) to upper (lower) boundary,, the greater the repulsive (attraction) force is. When the vehicle is in the middle of the road, the total force

from both sides of the road is 0. Suppose the upper bound is b_1, lower bound is b_2, the force between b_1 and vehicle i is F_{31}, the other is F_{32}, just as shown in Fig. 1.

Therefore, we can get the expression of F_3.

$$F_3 = F_{31} + F_{32} \tag{12}$$

Where,

$$F_{31} = \begin{cases} m_i A_2 exp\left(-\frac{w-y_i(t)}{w/2}\right), & w/2 < y_i(t) < w \\ -m_i A_3 exp\left(-\frac{y_i(t)}{w/2}\right), & 0 < y_i(t) < w/2 \end{cases} \tag{13}$$

And

$$F_{32} = \begin{cases} m_i A_4 exp\left(-\frac{w-y_i(t)}{w/2}\right), & \frac{w}{2} < (w - y_i(t)) < w \\ -m_i A_5 exp\left(-\frac{w-y_i(t)}{w/2}\right), & 0 < (w - y_i(t)) < \frac{w}{2} \end{cases} \tag{14}$$

Finally,

$$F_3 = \begin{cases} m_i A_2 exp\left(-\frac{y_i(t)}{w/2}\right) - m_i A_5 exp\left(-\frac{w-y_i(t)}{w/2}\right), & \frac{w}{2} < y_i(t) < w \\ 0, & y_i(t) = \frac{w}{2} \\ -m_i A_3 exp\left(-\frac{y_i(t)}{w/2}\right) + m_i A_4 exp\left(-\frac{w-y_i(t)}{w/2}\right), & 0 < y_i(t) < \frac{w}{2} \end{cases} \tag{15}$$

Where, A_2, A_3, A_4, A_5 are parameters of the system, and $A_2 = 1$, $A_3 = 20$, $A_4 = 2$, $A_5 = 15$. And w is the width of road, w is equal to 3.75 in general.

(4) In addition to controlling the initial vehicle speed, we also need to keep the vehicles in the model running within the range of speed limit like the actual situation of highway.

For the above reasons, we introduce the vehicle speed control model [26].

$$F_4 = \begin{cases} A_6 v_i(t-1), & when \quad v_i(t-1) < 15 \\ -A_7 v_i(t-1), & when \quad v_i(t-1) > 30 \end{cases} \tag{16}$$

Where, A_6, A_7 are positive constants, $A_6 = 2$, $A_7 = 4$, and the unit of $v_i(t-1)$ is m/s.

When the speed is too fast, for example, it exceed the maximum speed of highway, i will be subject to a force whose direction is opposite to that of the speed in order to ensure traffic safety.

When the speed is lower than a certain value, i will be subject to a force whose direction is the same as that of the speed, which is set to ensure high driving efficiency and avoid congestion.

3 Simulation and Analysis

The simulation experiments and analysis are all accomplished by MATLAB in this paper. At the beginning of the simulation, 10 cars are randomly generated in the initial simulation area of 20×200 m, the initial speed of all vehicles is set to be 15–30 m/s, and the simulation time is set to be one hour. In addition, the information of all vehicles is updated every 0.01 s.

3.1 Analysis of Vehicle Trajectory in Simulation

First of all, we establish a Cartesian coordinate system in the plane of road, and the x coordinate is lateral distance of road, y coordinate is longitudinal distance of road. The schematic view of vehicle locus is shown in Fig. 2(a) and (b) is an image obtained by enlarging the initial trajectory of the vehicle in Fig. 2(a), different curves represent the travel trajectories of different vehicles, we can see from the picture that the trajectories overlap together after the initial small amplitude swing. It indicates that vehicles are running in a row at this time. And it's consistent with the expected objectives of the paper. In addition, the total driving distance of vehicles is 110 km during the simulation time, and it is basically consistent with the actual situation of highway.

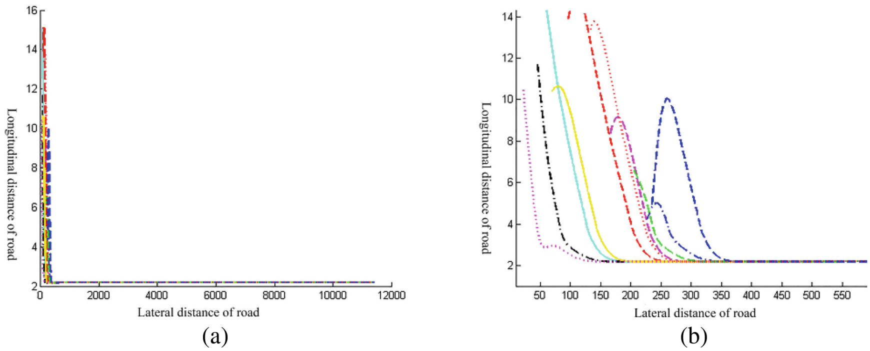


Fig. 2. (a). The schematic view of vehicle locus, (b). The initial trajectory of the vehicle in simulation

3.2 Analysis of Vehicle Speed in Simulation

Figure 3 shows the relationship between speed of vehicles and time, the horizontal axis represents time and the vertical axis represents vehicle speed. We can see that the speed remaining at 30 m/s finally. It is also consistent with the initial goals set by the simulation.

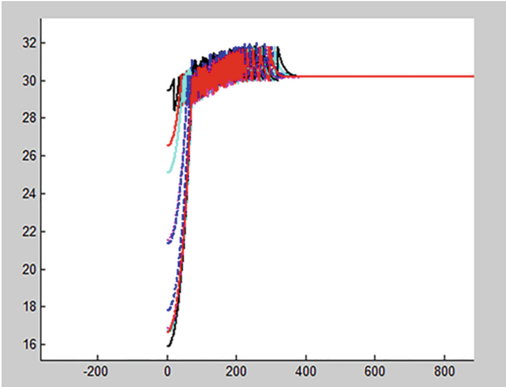
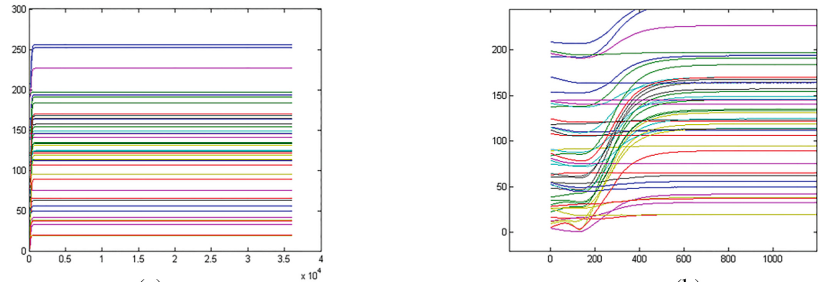


Fig. 3. The relationship between speed of vehicles and time

3.3 Analysis of Relative Distance of Vehicles in Simulation

Figure 4(a) is a graph showing the change in the distance between any two vehicles with time, there are $C_{10}^{2} = 45$ lines for ten vehicles. And the horizontal axis represents time and the vertical axis represents distances. We can see the distances between any two cars maintain stability finally. Likely, Fig. 4(b) is an image obtained by enlarging the initial distance between the vehicles in Fig. 4(a). And due to the instability of vehicle speed and location in the early simulation, the range of changes of vehicle spacing is large. The spaces of vehicles also maintain steady after the speeds become stable.



(a) (b)

Fig. 4. (a). The change in the distance between any two vehicles, (b). The initial distance between the vehicle in simulation

4 Conclusion

In this paper, the group moving model is established based on the fish behavior model and the actual situation of vehicle cruising, we not only ensure the speed, acceleration and trajectory of vehicles are all within the reasonable range during the simulation, but also make all vehicles driven in a line and ensure the stability of the vehicle, so that to avoid the collision between the front and rear vehicles. The results of simulation experiment are proved the feasibility of applying the theory of fish behavior to the research of cooperative movement of multi-vehicle in the environment of Internet of Vehicle.

In the other hand, there are still many shortcomings in the research of this paper. For example, we treat all the vehicles as an individual with the same motion characteristics, without considering the differences between vehicles. And further improvement is needed in the following studies.

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