Social Force Based Vehicle Model for Traffic Simulation

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Abstract

To simulate a heterogeneous traffic flow is a promising branch of the research of traffic flow modeling. Historically, the demand for this kind of models comes from developing countries in which mixed traffic flows are common; however, recently the demand also comes from developed countries where the concept of "shared space" becomes acceptable and popular. In order to make a progress in this field, the approaches based on macroscopic model, mesoscopic model, and microscopic are considered by various researches. For macroscopic model, the continuum model based on the porous flow is proposed. This model is able to describe the phenomenon of heterogeneous queues for cars and scooters. For mesoscopic model, several extensions on Cellular Automation (CA) model are proposed, and also focus on modeling the traffic flows with a mixture of cars and motorcycles.

The microscopic traffic flow model has several natural advantages in modeling heterogeneous flow. First, the microscopic models have already been applied to both vehicles and pedestrians, therefore a lot of successful experience can be inherited from those researches; second, aiming at describing the individual behavior of traffic participants, microscopic model is suitable for describing the difference between diverse traffic participants.

This paper is based on the preceding work in [1] [2]. An approach for modeling vehicle behaviors on the 2-dimensional space is proposed. A vehicle dynamic model is employed to simulate the attributes of vehicles, and extended social force model is adopted to describe the influence of environments on the simulated vehicle. In addition, several typical behaviors are tested and discussed in order to show the feasibility, prospects, and limitation of this approach.

Keywords: Microscopic traffic flow modeling; Social force; Vehicle dynamic model; heterogeneous traffic flow

1 Introduction

One of the most interesting challenges, which the microscopic traffic flow modeling method is facing, is to model the heterogeneous traffic flow. A traditional application of this method is to model a mixed traffic flow that includes cars, motorcycles, and bicycles. A newer application of this method is to analyze a "shared space", on which various traffic participants, such as motor vehicles, bicycles, and even pedestrians, share the same open space without any separating discipline. In order to analyze this kind of objects, a traffic flow model that describes the interaction among diverse traffic participants has to be established.

Various models have been discussed for modeling heterogeneous traffic flow. The Cellular Automation (CA) model, proposed by Nagel [3], has been extended for mixed traffic flow simulation. Lan [4] discusses using CA to simulate the mixed traffic flow with cars and motorcycles, but not pedestrians. This work can be considered as an extension on [3] for motorcycles, and it is suitable for those Asian cities with large amount of motorcycles. Zhang [5] discusses using CA to model the road crossing behavior of pedestrians, associated with its effects on vehicle traffic flow. Mallikarjuna [6] discusses the extension of CA for heterogeneous traffic modeling by allowing a vehicle to occupy more than one cells at the given instant of time. Another related work is that Nguyen [7] discusses an extension of social force model for motorcycle modeling, but without considering the mechanical dynamic attributes of motorcycles. Besides mesoscopic models, the topic of modeling the heterogeneous traffic flows are also considered in macroscopic traffic flow methods. Nair [8] presents a continuum flow model based on the porous flow. However, the original motivation of this research is also to model the mixed traffic flow that involves cars, motorcycles, but not pedestrians, and the approach can only describe limited phenomenon, such as the heterogeneous queue forming.

From the perspective of classification of traffic flow models, the models describing individual traffic participants directly are categorized as the microscopic model. Car-following based vehicle models are the main microscopic traffic modeling method currently; they are based on the principles of interaction between two adjacent vehicles. Besides the car-following, an independent lane-changing model is needed to describe the lane changing behavior. Car-following based vehicle model has been adopted in analysis of diverse traffic scenarios, especially the evaluation of traffic infrastructure. However, the existing problem that prevents it from application in the mixed traffic simulation is that it is one-dimensional, in other words, only considers the longitudinal behaviors. In a shared space application, the description of two-dimensional movements is necessary.

In contrast to vehicle simulation, the pedestrian simulation is a younger domain. Helbing [9] proposes Social Force model to describe an individual pedestrian as a physical particle, therefore, the "particle" moves in a force field that describes the interaction with both the other particles and its environment. This model describes typical behavior of crowds, even under the evacuating situation [10].

Another obstacle to applying a two-dimensional vehicle simulation comes from the mechanical attributes of motor vehicles. Because a vehicle is a four-wheel system, it cannot move on an arbitrary direction. This problem has been considered in the motor vehicle industry and the related research domains, for the purpose of simulating behaviors of a new designed vehicle without building it realistically. The developed vehicle dynamic models [11] are able to simulate the practical vehicle response to the control input (steering angle, pedal position, and so on) and environment (road surface condition, wind influence, and so on), based on the basic parameters of a vehicle. Those vehicle dynamic models have been widely used for vehicle design, accident evaluation, auto racing simulation, and so on.

Schoenauer [12] proposed a concept of introducing the social force into vehicle flow modeling. Based on the modified social force, the influences of infrastructure, obstacles, and other traffic participants can be exerted on a simulated vehicle. In addition, a game theory based model is used to model the tactical behavior of drivers. Huang [1] [2] inherits the idea of extension of social forces for vehicles; however, Huang pays more attention on improving the definition of social forces for vehicles and vehicles behaviors on operational level.

This paper presents an approach (based on [1] [2]) for modeling vehicle behaviors on two-dimensional space. In addition, this work considers the dynamic attributes of vehicles, in order to describe the limitation of mechanical attributes on vehicles behaviors. The proposed approach is tested with various scenarios to evaluate the feasibility, prospects, and limitation of this approach.

Section 2 of this paper describes the structure of the proposed approach and the models that are integrated into the framework, including vehicle dynamic model, extended social force model, road /space description, and several considerations for improving the stability of the model. Section 3 tested the proposed approach with 4 typical scenarios. Section 4 presents conclusions and recommendations for further research.

2 Methodologies

2.1 Simulation framework

In order to simulate vehicles behaviors on a 2-dimensional space, a simulation framework that is different to the traditional 1-dimensional microscopic traffic flow model is necessary. The framework used in this paper is designed from the perspective of the simulated vehicle (Figure. 1).

The steps included in Figure 1 are explained as following:

- Vehicle initialization: the data structure containing the data for describing vehicles status is initialized;
- Vehicle movement: to move a vehicle for one time step, based on the vehicle dynamic model and control input;
- Position evaluation: recognize in which area the vehicle is; in addition, assign the target point, and filter the obstacle list;
- Tactical decision: based on the position evaluation, the simulated vehicle makes the tactical level decision, such as stop or start, following or overtaking, and so on. This step will not be included in this paper. A simplified emergency stop strategy is adopted, when it is necessary.

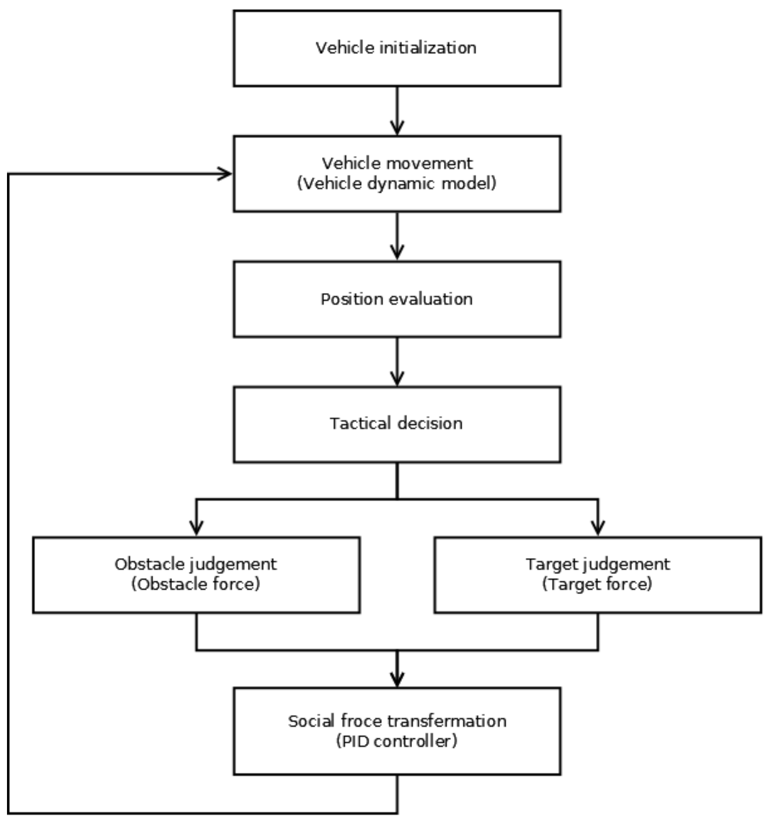

Figure 1: System framework

- Obstacle judgments: calculate the obstacle force exerted on the simulated vehicle;
- Target judgments: calculate the target force exerted on the simulated;
- Social force transformation: to transform the resulted social force into the control input (steering angle) by applying a typical PID controller.

2.2 Road / space description

A 2-dimensional space has to be described for the simulated vehicles. This space is represented by several coterminous polygon areas, which divide the road or shared space into several zones. For each zone, two basic elements have to be defined: first, one target point has to be assigned, but the target point does not have to be static (discussed in section 2.7.1). Second, desired speed should be predefined; in addition, in order to make the definition more flexible, each zone can have different desired speed for specific subarea. The desired speed is used to influence the speed of the simulated vehicles. At current progress, simplified acceleration and deceleration are adopted with a vehicle, if its current speed does not equal the desired speed of the located zone. In Figure 4, an example is shown. In this example, a T-intersection is divided into two zones. Each of them is assigned a target point. The location of the boundary between zone 1 and zone 2 is determined by the place on which a vehicle starts to turn. This principle is determined by the nature of this developed approach, which is to simulate the most spontaneous behavior on operational level.

2.3 Vehicle dynamic model

Vehicle dynamic models are used to describe the response of a vehicle to its control input. These models are widely researched in the automotive industry, in order to evaluate the performance of a vehicle or driving behaviors without experiments with real cars. This paper is based on a typical linear single-track model described in [11]. This model is capable of describing the response of a vehicle in general condition, especially when the vehicle speed is relatively low ($\leq 10m/s$).

Figure 2 shows the single-track vehicle dynamic model. X-Y is a ground fixed coordinate; x-y is a local coordinate that is fixed on the gravity center of the vehicle, and the x-axis points to the longitudinal direction of the vehicle; two front wheels (two rear

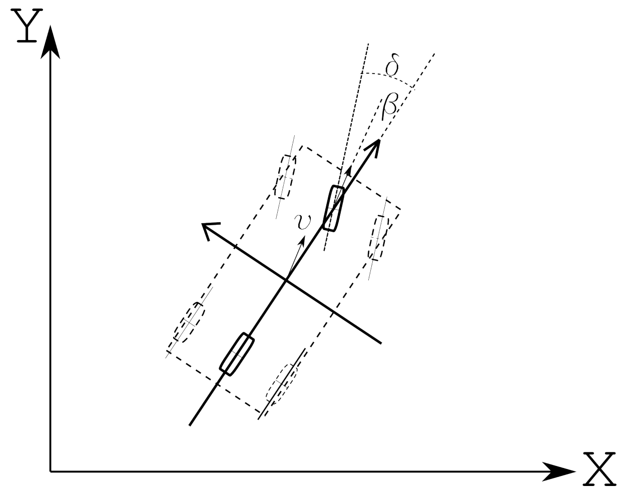

Figure 2: Two-wheel dynamic model

wheels) are projected to x-axis, by this a four-wheel model is simplified as a two-wheel one (single-track); θ is the rotation angle of the vehicle body; β is the angle between the velocity direction and longitudinal direction of the vehicle (side slip angle); and δ is the steering angle; and δ are both according to the x-y coordinate. Input of this model includes steering angle and speed control. Output of this model is the state of vehicle for each simulation step, including side slip angle and rotation angle.

This model is formulated as first ordered linear differential equations (Equation 1) [2]. The necessary parameters are collected in [14] by measuring different types of realistic cars. Refer to [1] for more information.

$$\begin{bmatrix} \dot{\beta} \\ \dot{\gamma} \end{bmatrix} = \begin{bmatrix} -\frac{K_f+K_r}{mv} & -1-\frac{1}{mv^2}(l_f K_f - l_r K_r) \\ \frac{-l_f K_f + l_r K_r}{I} & -\frac{l_f^2 K_f + l_r^2 K_r}{Iv} \end{bmatrix} \cdot \begin{bmatrix} \beta \\ \gamma \end{bmatrix} + \begin{bmatrix} \frac{K_f}{mv} \\ \frac{l_f K_f}{I} \end{bmatrix} \delta \qquad (1)$$

Where:

β: The body side slip angle $[rad]$, the angle between the longitudinal direction of the vehicle (x-positive axis) and the speed direction.

v: running speed of vehicle $[m/s]$;

γ: Yaw rate of vehicle $[rad/s]$, the angular velocity of vehicle around its own center of gravity;

K_f, K_r: Cornering stiffness of front/rear tires $[N/rad]$; these two variables describe the relation between the tire slip and the force generated by the tires;

m: The mass of vehicle $[kg]$;

l_f, l_r: The distance between front/rear axles and center of gravity $[m]$;

I: The rotation moment of inertia $[kg \cdot m^2]$ of the vehicle, around its center of gravity;

δ: Steering angle $[rad]$.

2.4 Extended social force model for vehicles

By extending the concepts of the social force, this paper presents a group of new definitions of social forces for vehicles, in order to improve the definition proposed in [2]. Two types of basic forces are defined: target force and obstacle force.

2.4.1 Target force

A target defined in this model is a point at which the simulated vehicle wants to arrive. This object is represented by a 3-dimensional vector, which includes the x coordinate, the y coordinate, and the direction. Correspondingly, the target force is the force that leads the vehicle to its desired destination. This force includes two components: the location force (Equation. 2) and the direction force (Equation. 3).

$$\vec{F}_{loc}(t) = \alpha_1 \left[\|\vec{v}(t)\| \cdot \frac{\vec{r}(t)}{\|\vec{r}(t)\|} - \vec{r}(t) \right] \tag{2}$$

$$\vec{F}_{dir}(t) = [0; \alpha_2(\,\theta_{tar} - \theta(t)\,)] \tag{3}$$

$$\vec{F}_t(t) = \begin{cases} \vec{F}_{loc}(t) & \textbf{if } \|\vec{r}(t)\| > d_f \\ \frac{1}{d_f - d_n} \left[(\|\vec{r}(t)\| - d_n) \cdot \vec{F}_{loc}(t) + (d_f - \|\vec{r}(t)\|) \cdot \vec{F}_{dir}(t) \right] & \textbf{if } d_n \leq \|\vec{r}(t)\| \leq d_f \\ \vec{F}_{dir}(t) & \textbf{if } \|\vec{r}(t)\| < d_n \end{cases} \tag{4}$$

Where, $\vec{v}(t)$ is the current speed vector; $\vec{r}(t)$ is the position of the target according to the car-fixed coordinate; therefore, $\|\vec{v}(t)\| \frac{\vec{r}(t)}{\|\vec{r}(t)\|}$ is the ideal moving direction for the vehicle at time t; θ_{tar} is the target direction; $\theta(t)$ is the current direction (rotation angle); $\vec{F}_{loc}$ is the social force attracts the vehicle heading to its target; $\vec{F}_{dir}(r)$ is the social force make the vehicle have the desired rotation angle. Several points need clarification:

- Target points only affect the direction of a vehicle through steering angle, but not the speed. The speed of a vehicle is affected by two factors: the desired speed in the current zone; the emergence distance to an obstacle. The ideas involved in car-following model can be adopted to describe the speed determination. This topic is not discussed in this paper.

- A driver has his/her own visible angle. If an obstacle's location is out of his/her field of view, it will be ignored. Currently, the field of view is defined as 180 degrees. We suppose a driver on a shared space will give more attention to the obstacles than on normal roads, which means his field of view is larger when he is on shared space than on normal roads.

- Based on this definition, it is obvious that the distance from the vehicle to its target does not influence the target force. In this design, an assumption about the operational level behavior is made: "a driver will change his direction as early as possible to fit the final destination".

- For each target, besides the location (x-y coordinate), it also has a third dimension: the direction. This item describes a vehicle's ideal direction when it arrives at its target.

- As shown in Equation 4 When the target is far away enough from the vehicle ($\|\vec{r}(t)\| > d_f$), only the location force take effects; on the other side, when the target is near enough from the vehicle ($\|\vec{r}(t)\| < d_n$), only the direction force take effects; between the distance thread, a linear function is used to combine these forces, in order to obtain a gradually shift.

2.4.2 Obstacle force

An obstacle refers to an object that should push the simulated vehicle away from it, in order to avoid collisions. In addition, an obstacle can be static or moving. In other words, the obstacles are a general expression of various kinds of objects existing on the space, including pedestrians, static obstacles, other vehicles, road infrastructures, bollards, and so on.

The definition of obstacle force is shown in Equation 5.

$$\vec{F}_p(t) = \begin{cases} -\beta_1 \cdot \exp\left(-\frac{\|\vec{r}_p(t+\Delta t)\|}{\beta_2}\right) \cdot sign\left(\vec{r}_p(t+\Delta t)\right) & \textbf{if } \|\vec{r}(p+\Delta t)\| \geq \|\vec{r}_p\| \textbf{ and } l_1 \leq \|\vec{r}_p(t+\Delta t)\| \leq l_2 \\ [0;0] & \textbf{if } else \end{cases} \tag{5}$$

Where, β_1 is the length parameter, which expresses the maximum repulsive force an obstacle can generate, the value is determined by comparing it with target forces; β_2 is the distant parameter, which affects the sensitivity of vehicles to obstacles; $\vec{r}_p(t+\Delta t)$ is the position of the obstacle on next time step (noticing that both the obstacle and current vehicle are moving); $sign()$ is the sign of the vector;l_1 and l_2 are two distance thread hold.

Several points need clarification:

- In order to reduce the number of obstacles that has to be processed, several conditions have been set when calculating the resulted obstacle force. First, the system judges whether the obstacle moving towards to the current vehicle, if it is moving away from it, it does not exert a force; second, the system judges the distance from an obstacle to the simulated vehicle, if the distance is longer than the threshold l_f, the force is set to be zero, at the same time, if the distance is shorter than the threshold l_n, the vehicle is under the braking situation, therefore the obstacle force is also zero (under this situation, the vehicle is controlled by emergency stop).
- It is necessary to calculate the obstacle force according to the position of current vehicle on next time step (maybe more); it is a reasonable assumption that compensates the weak point of PID controller than a real human control behavior.
- At current progress, the obstacle force on longitudinal direction (the x-componnent of the force vector) is not discussed in details. Instead, a concise strategy is adopted: if the simulated is within the emergency distance to any obstacles, it will brake and stop instantly.

2.5 PID controller for transformation from social forces to steering angle

A typical PID controller is adopted to transform the social forces to control input (steering angle). The equation for PID controller is shown in Equation 6. The social force $F_s(t)$ is used as the input of the PID controller, in other words, the measured "errors".

$$s(t) = K_p F_s(t) + K_i \int_{t_0}^{t} F_s(\tau) d\tau + K_d \frac{d}{dt} F_s(t) \tag{6}$$

$$F_s(t) = A \cdot \left[\vec{F}_t(t) + \sum_{p=1}^{n} \vec{F}_p(t) \right] \tag{7}$$

Where, $A = [0\ 1]$. Refer to [2] and [13] for more detailed information about PID controller and the application with the current work.

One point worth noticing is that under the control of PID, a vehicle responds to the target force as soon as possible. This means all the expected active turning behaviors should be described by adding necessary target point.

2.6 Vehicles' behaviors on operational level

The modeling of vehicles' behavior is related to wider areas, not only the traffic simulation research. In auto vehicle industry and technology, the vehicles' behavior is researched for evaluation of vehicle performance; in traffic safety, vehicles' behavior is researched from the perspective of accidents. In traffic flow modeling, car-following behavior and lane changing behavior are mostly reported. Toledo [14] summaries the vehicles' behaviors related to car-following model. Acceleration and lane changing are two main behaviors discussed in this dissertation. However, these two behaviors are for the one-dimensional behavior. Car-following model describes the vehicle's behavior as a following behavior that is explained as a vehicle changes its speed according its preceding vehicle. Schoenauer [12] proposes an idea about distinguishing the difference between operational level and tactical level; and Huang [2] focuses on describing the operational level behaviors. In this paper, the driver behaviors on operational level will be discussed in advance.

During the process of designing and evaluating the simulation approach, the author tries to limit the behaviors that are influenced as few as possible by the driver's personal character, but only the necessary behavior when facing a typical scenario or described as the spontaneous behavior. At least 3 kinds of behaviors can be summarized here: necessary turning, static obstacle passing/overtaking, and gap entering.

The necessary turning refers to a basic turning behavior, such as turning at an intersection. The key point for "necessary" is that the vehicle is only influenced by the road structure but not other vehicles or pedestrians. Therefore, the driver only does the necessary turning behavior without changing his/her tactical (such as stop and give the way to a pedestrian). Static obstacle passing refers to the behavior that when a driver sees an obstacle in front of him/her , and make the necessary response to pass around it without conflict. The avoiding behavior also only includes the necessary action. The overtaking is an extension of static obstacle passing; it described the behavior that a faster vehicle overtakes its low speed preceding one, such as a bicycle or another vehicle. The gap entering refers to the behavior when a vehicle facing several obstacles or vehicles in front of him, the vehicle may utilize the gap among them to move forward.

2.7 Stability consideration

Based on the experiments on the proposed framework, the stability problems of vehicle emerge. When a simulated vehicle face a scenario with big amount and random positioned obstacles, a very odd trajectory is possible to be obtained. For example, a vehicle will run into a narrow slot between to obstacles where the width of it is not enough for its size. In other examples, a vehicle is possible to run over an obstacle. The reason of these problems may be that the proposed approach can only make the vehicle to find one possible trajectory, but cannot make sure the trajectory is the best one. In order to solve this problem, several additional principles are added, the simulation results show an improvement brought by these principles.

2.7.1 Target planning

The location of target points has to be determined by a planning process. Because the turning behavior starts as soon as possible if the target force is not zero, the planning plays important role in the performance of the model.

As mentioned before, a target point is used to generate the target force that guides the vehicle to its desired location. However, a strictly fixed location of the target point does bring some realistic problems. As mentioned in section 2.2, one target is assigned to each zone. Several targets have to be defined for guiding a vehicle to get across an area. There are several principles for the target planning:

- The target is on the target edge. The target edge is the edge of a zone polygon that covers all the possible location of the target point. In addition, the location of the target is determined by the “low potential tunnel” principle.

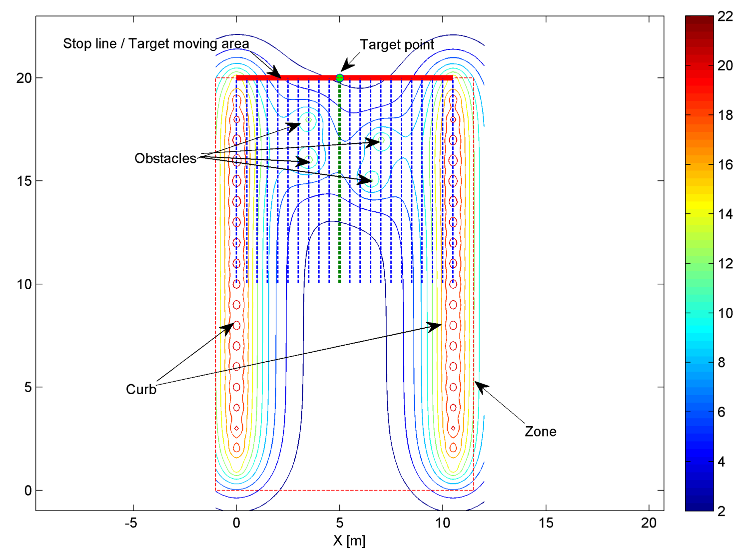

Figure 3: Low potential tunnel for determining target point location

- Low potential tunnel principle: Figure 3 shows an obstacle force based potential field. In this figure, the vehicle is supposed to head to positive direction of Y axis (according to the ground fixed coordinate, rotation angel = 90 degrees). Therefore, a potential field of obstacle force can be defined. The points that have highest potential are the centers of obstacles. As shown in Figure 3, because the road curb is described by a sequence of closely distributed obstacles, the potential of them is higher than those single obstacles. Several obstacles located on the road also have high potential. In addition, several evaluation lines are generated automatically. Each of the evaluation lines starts from one of the possible target points, which are evenly distributed on the target edge, and is perpendicular to the target edge. In addition, the lengths of lines are restricted (in Figure 3, 10m is used as the limitation). As seen in this figure, the green dashed line is the one with lowest potential; therefore the green point (marked with Target point) is the chosen target point.

- The potential field only has to be evaluated once when the simulated vehicle runs into the sensitive area (the current zone); before that, the target point is located in the middle point of the target edge.

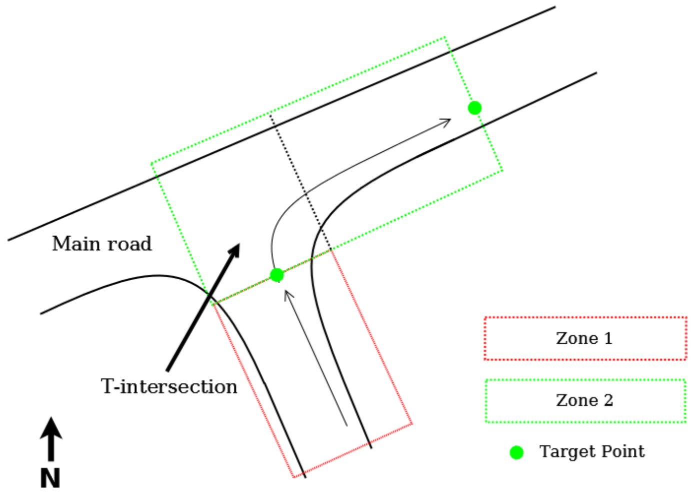

Figure 4: Test area (from [2])

2.7.2 Obstacle aggregation

When several obstacles are located very close, the results force may lead the vehicle to get across from the narrow slot. This behavior is not anticipated, and will bring unreasonable trajectory. In order to avoid this situation, an obstacle aggregation process is defined. One or more extra obstacles will be added between the two close obstacles if the distance between them is shorter than a predefined threshold.

3 Model performance

3.1 Turning behavior

The turning behavior is one of the most basic behaviors. During this behavior, a vehicle should make a turning in order to head to the desired direction. A test has been made in [2] as shown in Figure 4 and Figure 5.

This test simulates a very basic turning behavior at a T-intersection. The road situation comes from a practical example. In the test, a vehicle runs from south entrance of the intersection, and then, it turns right. The general situation of road is shown in Figure 4, and more information can be seen in [2]. Data collected in the realistic situation are used to generate an average trajectory for reference, which is shown as the red dashed line in Figure 5. Targets are predefined based on the road situation. The simulated trajectory is illustrated in Figure 5, which match the field trajectory well.

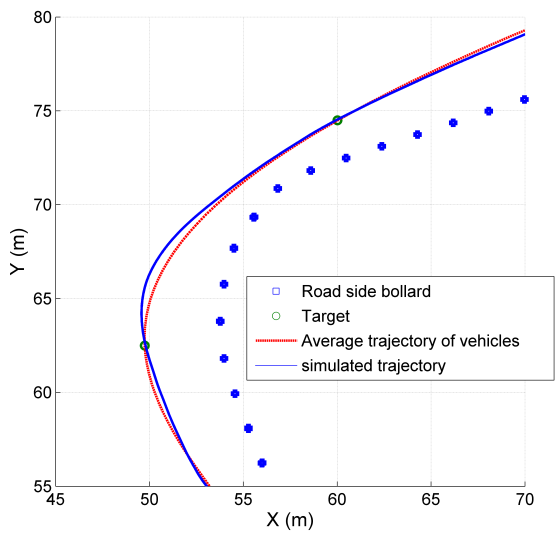

Figure 5: Turning behavior (from [2])

As explained before, the developed model only reproduces the most basic behaviour of a vehicle. When a vehicle is assigned with a target point to which it is not heading, the vehicle will responds as soon as possible to turn. In this tested example, two targets points are added. The first one is close to the stop line, and the second one is on the main road. If the first target point does not exist, the vehicle will start to turn at the first time step, and this is not expected.

3.2 Obstacle passing / Overtaking behavior

Obstacle passing behavior and overtaking behavior are both basic operational level behaviors the developed model should be able to describe.

Figure 6 shows a tested example for static obstacle passing. In this example, the vehicle speed is set to be $5m/s$. The target point is located at $[0, 15]$, the obstacle is located at $[0, 7]$. The simulated trajectory shows the vehicle changes its path to avoid a collision with the obstacle as expected.

Figure 7 shows a more complex but similar scenario as the first one. A vehicle is running to its target with a speed of $10ms$, and just in front of it ($[0, 6]$), a slow vehicle (for example, a bike) is running with the speed of $5m/s$ on the same direction. The simulated trajectory shows that the vehicle overtakes the bike and come back to its original lane in order to reach its destination.

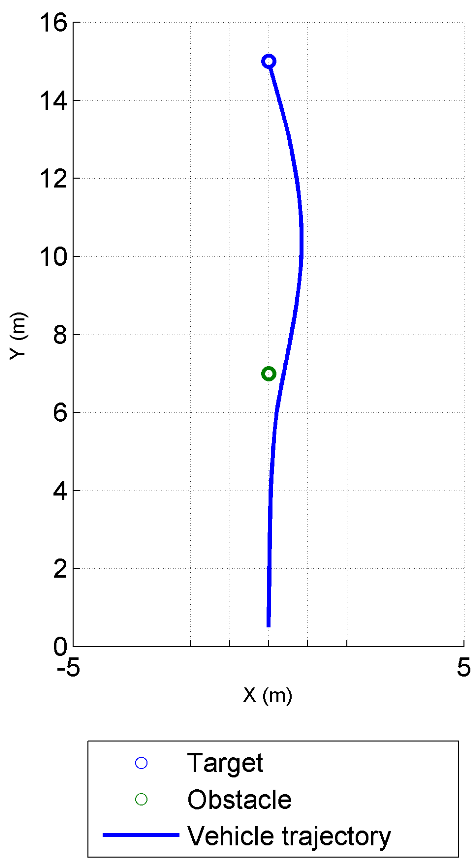

Figure 6: Static obstacle passing (from [2])

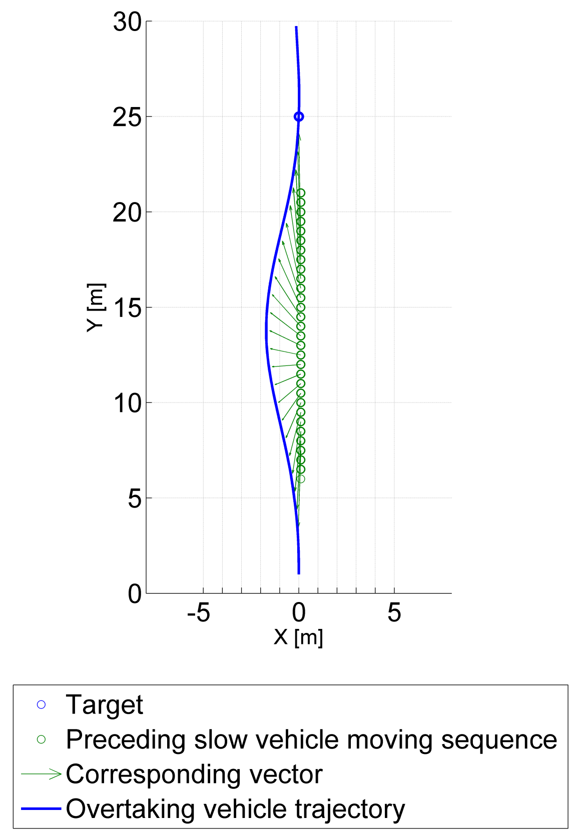

Figure 7: Overtaking (from [2])

3.3 Heterogeneous queue forming behavior

The heterogeneous queue forming is a typical phenomenon when simulating a mixed traffic flow. Under this situation, a small vehicle can utilize the gaps among the other vehicles already in the queue to get a stop place that is more close to the stop line. Although this behavior is difficult to be distinguished between operational level and tactical level, the behavior of entering a possible gap can be considered to be spontaneous.

In the test (Figure 8), 4 groups of obstacles are used to represent the vehicles that already wait in the queue. The simulated vehicle is moving forwards to the stop line, until

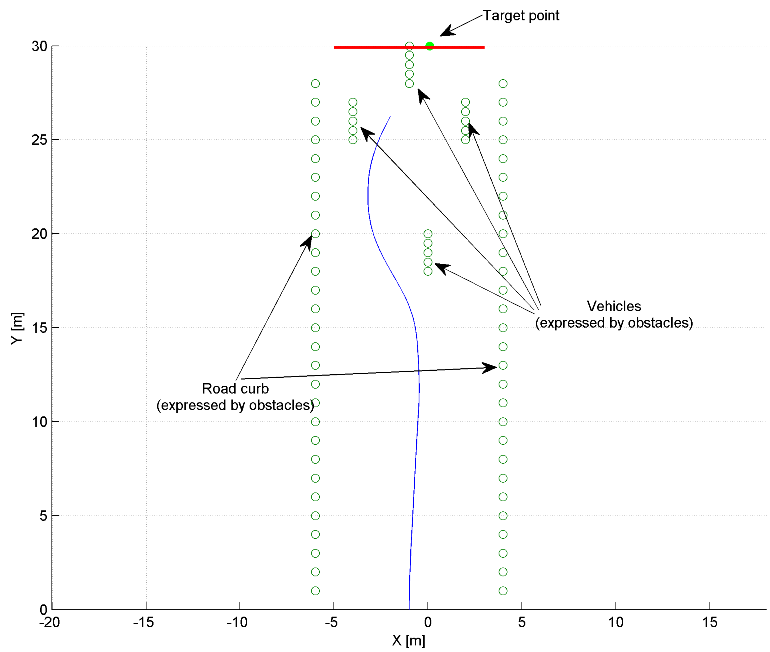

Figure 8: Heterogeneous queue forming

the emergency stop condition is fit. The speed of the vehicle is set to be 5 m/s.

3.3.1 Area passing with randomly distributed obstacles

The proposed framework combines 3 basic components: the social force, the PID controller, and the vehicle dynamic model. Therefore, whether the proposed model produces a reasonable vehicle trajectory under various situations is concerned. Based on the experiments that have been done, there are some examples in which the proposed framework produces trajectories that are against common sense. However, the successful examples are dominant.

In order to evaluate how often an odd trajectory is obtained, a group of random tests is operated. In those tests, the road structures same to Figure 8 are adopted. On the road area, 10 obstacles are spread randomly from 3 to 20 meters away from the stop line. And this test is repeated for 50 times to see how many odd trajectories are obtained. Those trajectories, on which the vehicle runs over obstacles, are considered as odd one. In addition, the emergence stop is blocked in this test, otherwise the vehicle will never runs over an obstacle. In the 50 tests, an example of acceptable trajectory is shown in Figure 9, however, 5 examples (10%) are observed with odd trajectories in which the simulate

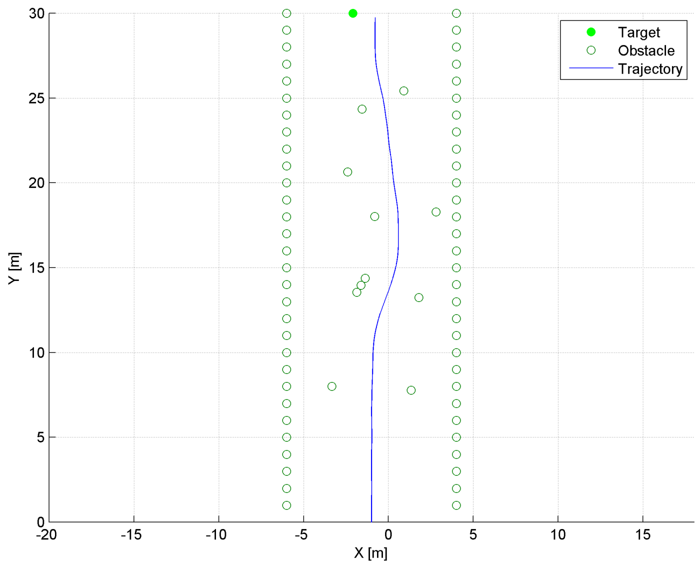

Figure 9: A typical good trajectory

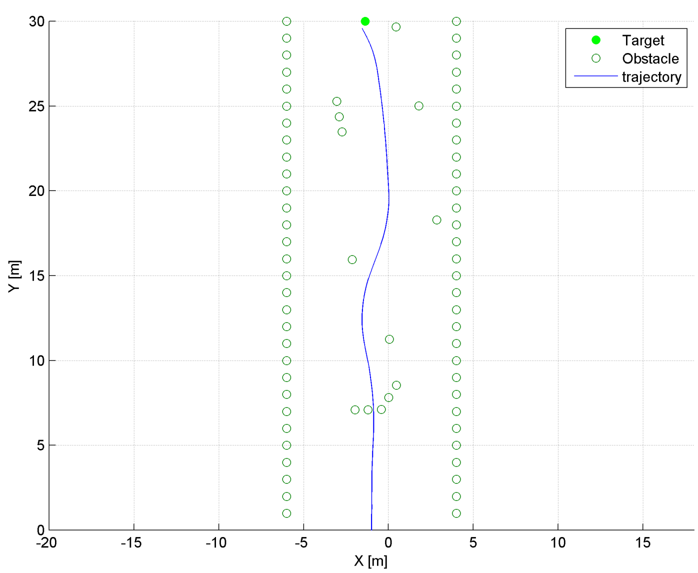

Figure 10: An odd trajectory

vehicle runs over an obstacle that should be avoid, a typical example is shown in Figure 10.

4 Conclusions and discussions

In this paper, an approach for simulating vehicle on a 2-dimensional space is proposed and evaluated. This approach focuses on simulate the vehicles behavior on operational level, and focuses on the lateral behavior (turning behavior). Three basic operational level behaviors, including turning, obstacle passing / overtaking, heterogeneous queue forming are described by the proposed model. The obtained trajectories show that the basic attribute of those behaviors are described. A serious of test with randomly distributed obstacles is made to see how often and in which form an unreasonable trajectory is generated.

The behaviors described by the proposed approach are on operational level, in other words, they are the spontaneous behaviors, which are not significantly affected by the individual attributes of a specific driver. This limitation relates to another important assumption that a simulated vehicle responds to a target point as soon as possible when it is not heading to its targets. The direct consequence of this fact is: the location of the target point influences the behavior of the simulated vehicle most significantly, which means the target points planning plays an important role in influencing the final performance.

Till now, the proposed approach focuses on the lateral behavior of vehicles, and simplified the longitudinal behavior, which is widely discussed by the traditional 1-dimensional vehicle simulation models. The author is hoping for a combination of car-following model (for longitudinal behavior)and the developed model (for lateral behavior, social force based); even a hybrid model that allows a transformation between one-dimensional model and two-dimensional model, is supposed to be promising.

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