The ego vehicle trajectory plan interacting with the bicycle at a single-lane road

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I. Introduction

At present, driving safety and traffic congestion, researchers tend to develop vehicles from manual driving to autonomous driving. The vehicle functions are gradually improved, including the initial research on vehicle antilock brake system (ABS), to adaptive cruise control (ACC), lane changing, etc. However, different countries have different traffic problems. In the Netherlands, single-lane narrow roads are very common as shown in figure 1.

Figure 1. single-lane narrow road in Netherlands.

This kind of road can only allow one vehicle to drive in the vehicle lane. Therefore, when encountering an oncoming vehicle, the ego vehicle needs to merge to the bicycle lane. After meeting the vehicles, it returns to the vehicle lane as shown in figure 2. So, the targets are finding a suitable gap to allow the vehicle to merge into the bicycle lane and planning a suitable trajectory for vehicle to merge into the bicycle lane. Therefore, the controller should be designed to obtain the speed and front wheel angle of the ego vehicle.

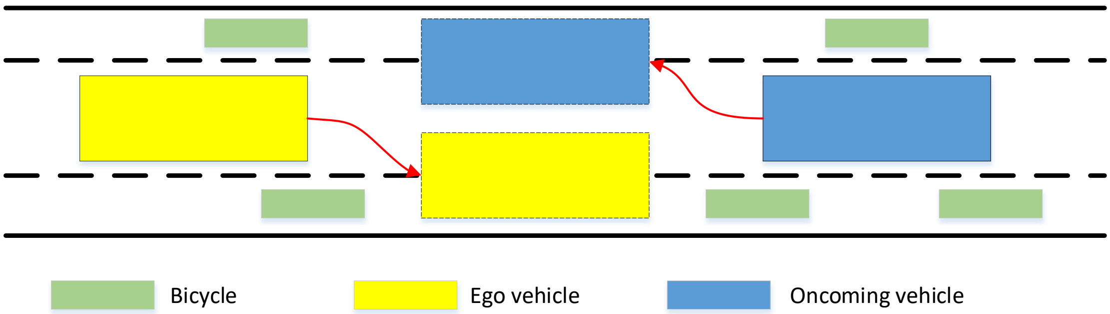

Figure 2. Schematic diagram of vehicle merging into bicycle lane

II. Lane change controller design based on MPC

We assume that the oncoming vehicle is a fixed obstacle, and the bicycle travels at a given speed and acceleration. So, the problem is simplified to forcing the vehicle to merge into bicycle lane within a fixed distance before driving to the obstacle. The two-degree-of-freedom vehicle dynamics and motion equations are established to describe the vehicle motion state which shown as equation (1).

$$\begin{cases} m\ddot{y} = -m\dot{x}\dot{\varphi} + 2[C_{cf}(\delta_f - \frac{\dot{y}+a\dot{\varphi}}{\dot{x}}) + C_{cr}\frac{b\dot{\varphi}-\dot{y}}{\dot{x}}] \\ m\ddot{x} = -m\dot{y}\dot{\varphi} + a_x \\ I_z\ddot{\varphi} = 2[aC_{cf}(\delta_f - \frac{\dot{y}+a\dot{\varphi}}{\dot{x}}) - bC_{cr}\frac{b\dot{\varphi}-\dot{y}}{\dot{x}}] \\ \dot{Y} = \dot{x}\sin\varphi + \dot{y}\cos\varphi \\ \dot{X} = \dot{x}\cos\varphi - \dot{y}\sin\varphi \end{cases} \tag{1}$$

where m is the vehicle mass; φ is the yaw angle; I_z is the vehicle yaw moment of inertia; a,b are the distances from center to front and rear tires respectively; X,Y are the positions in the global coordinate system; x,y represent the longitudinal and lateral displacement of the ego vehicle in the vehicle coordinate system; a_x represents longitudinal acceleration; C_{cf},C_{cr} represent steering stiffness of front and rear wheels.
In order to make the ego vehicle pass safely and quickly, and have a small impact on the bicycle, the following objective function is designed as equation (2).

$$J = \omega_1 J_1 + \omega_2 J_2 + \omega_3 J_3 + \omega_4 J_4 + \omega_5 J_5 \tag{2}$$

J_1: Minimize time on bicycle lane
J_2: Minimize the reciprocal of travel distance in 20s
J_3: Minimize the reciprocal speed at the end of the road
J_4: Minimize the acceleration
J_5: Minimize the jerk
$\omega_n, n=1,2,3,4,5$ represent the weight coefficient.
According to the safety constraints, traffic rules and the vehicle parameters, the following constraints are designed.
According to traffic rules, the longitudinal speed of the vehicle cannot exceed the road speed limit. It is usually $30km/h$ ($8.3m/s$).

$$0 < v_x < v_{x,\max} \tag{3}$$

In order to prevent the vehicle from rolling over and ensure lateral stability, the equation (4) and (5) could be obtained

$$-v_{y,limit} < v_y < v_{y,limit} \tag{4}$$

$$\delta_f < 0.4g \tag{5}$$

In order to ensure that the ego vehicle changes lanes in front of the oncoming vehicle, the equation (6) is designed

$$x_{min} < x < x_{max} \tag{6}$$

To prevent the ego vehicle from crashing into the road boundary, the equation (7) is given.

$$0 < y < y_d \tag{7}$$

After comprehensive consideration of the objective function and constraints, the following optimization problems need to be solved in each simulation step:

$$\begin{cases} \min J \\ s.t. 0 < v_x < v_{x,\max} \\ -v_{y,limit} < v_y < v_{y,limit} \\ \delta_f < 0.4g \\ x_{min} < x < x_{max} \\ 0 < y < y_d \end{cases} \tag{8}$$