Research on Vehicle Trajectory Tracking Control in Expressway Maintenance Work Area Based on Coordinate Calibration

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Abstract: In the highway maintenance work area, how to reduce traffic congestion and traffic accidents caused by vehicle changing lanes has become a continuing research issue. This research focuses on the lane-changing behavior of vehicles in the highway maintenance work area. By changing the lane-changing trajectory of vehicles under different lane numbers, it can intuitively understand the influence of different lane numbers on lane-changing characteristics. Studies have shown that when the number of highway lanes increases, the distance between the starting point of the vehicle lane change and the highway maintenance work area will increase. At the same time, the probability of changing lanes in front lanes that are barrier-free and does not need to change lanes decreases as the number of overlapping lanes increases. Under the condition of the same number of lanes, the closer the distance between the vehicle and the obstacle lane, the more convergent the lane-changing trajectory of the vehicle, and the probability of lane-changing greatly increases.

1. Introduction
With the increasing popularity of vehicles and the widespread application of vehicles in various fields, people have higher and higher requirements for driving safety. How to reduce traffic accidents and improve congested traffic has become a hot issue in the transportation system [1]. Aiming at the trajectory tracking control of highway vehicles [2-3], with the help of related technologies, the appropriate vehicle trajectory tracking algorithm is designed using vehicle status information to ensure that the vehicle completes the established tracking target. They regard the vehicle as an independent node, and focus on vehicle state information to design a trajectory tracking controller to ensure trajectory tracking performance [4-6]. However, the current research lacks the study of lane changing in expressway maintenance work area, lack of intuitive trajectory control map to show the relationship of vehicle lane change in expressway maintenance work area, and lack of research on the impact of the number of lanes in expressway maintenance work area on vehicle lane changing characteristics. The impact of the number of lanes on the lane-changing characteristics of the vehicle has not been considered for the time being. Ignored when designing the trajectory tracking controller, resulting in negative position tracking error and negative speed, which means that the safety distance between vehicles cannot be guaranteed, and more serious A rear-end collision may occur. Starting from the interactive data of the number of lanes and trajectories, this research analyzes the influence of the number of lanes on lane changing behavior in expressway maintenance operation areas, which is positive for analyzing the behavior of vehicles in expressway maintenance operation areas and reducing accident behavior in expressway maintenance operation areas. effect.
2. Problem Description

2.1. Lane change driving strategy
In the actual traffic environment, when the vehicle encounters a lane change obstacle in the maintenance work area in front of the vehicle, the vehicle needs to change lanes. As shown in Figure 1, when there is a maintenance work area obstacle warning in front of the leader's vehicle, the leader's vehicle needs to drive from the current lane to the adjacent lane. In particular, in order to ensure that the vehicle safely completes the lane-changing strategy, the vehicle should avoid excessive lateral acceleration during lane-changing driving to prevent the vehicle from sliding. In order to find a feasible lane-changing trajectory during the lane-changing operation of the vehicle and keep the vehicle driving smoothly, in this research, a polynomial algorithm is used to generate the lane-changing trajectory of the vehicle. The vehicle performs lane change at a certain longitudinal speed. $c_i$ is the end time of the vehicle lane change and depends on the driver’s comfort and driving safety. The 5-DOF vehicle lane change strategy is as follows:

$$f(x, t) = \sum_{i=0}^{5} b_i \times t^i$$
$$f(y, t) = \sum_{i=0}^{5} c_i \times t^i$$

(1)

Figure 1 Lane change driving strategy

2.2 Composition of maintenance work area
This research selects two-way four-lane, six-lane, and eight-lane highway maintenance work area with closed inner lanes as the research object. As shown in Figure 2, the maintenance work area is composed of Warning area, Upstream transition zone, Buffer, Work area, Downstream transition zone, and Termination zone.

Figure 2 Composition of maintenance work area

In order to collect the collected video data, use George2.1 video processing software to calibrate the coordinate coefficients, and extract the vehicle trajectory data by playing the collected data at low frames. Each vehicle is replaced with a punctuation in the figure, and the driving trajectory is determined by the x, y axis movement coordinates of the punctuation, and the driving trajectory of the vehicle is drawn based on the collected data. Figure 3 is a schematic diagram of trajectory data acquisition using
George2.1 video processing software.

Figure 3. Schematic diagram of George2.1 data extraction

3. Research on vehicle lane changing trajectory in expressway maintenance work area based on coordinate calibration

Extract 600 vehicle trajectory data from the data collected by George2.1, and divide the vehicle lane change into two types: mandatory lane change and non-mandatory lane change. Among them, the forced lane change refers to the behavior of changing lanes when the vehicle is in the lane requiring maintenance when it is above the vehicle to the high-speed maintenance operation area. After receiving the warning from the maintenance operation area, the vehicle needs to merge from the lane to the non-maintenance lane. Non-mandatory lane changing refers to the driving behavior that the vehicle is in a non-maintenance lane when the vehicle is driving to the high-speed maintenance area. After receiving the warning from the maintenance area, the vehicle autonomously chooses whether to change lanes. The driving trajectories of 4-lane, 6-lane and 8-lane are shown in Figure 4, 5 and 6 respectively. The trajectory data starts in the warning zone and ends in the work zone. The width of the lane is 1.6m, the ordinate is the cross section of the lane, the abscissa is the coordinate of the study section, and the difference of the abscissa at the intersection of the vehicle trajectory and the upper and lower dashed line 0.8m on the lane line is L.

3.1 4-lane highway maintenance work area

The 4-lane maintenance work area is shown in the figure. All vehicles in lane 1 need to change lanes to lane 2. At this time, vehicles in lane 1 are forced to change lanes. In the 4-lane lane change type 2 can be seen from the figure, at the X axis -130m, the forced lane change is all started, and at the X axis -105m, the forced lane change is completed. The lane change length L is about 30m.

Figure 4 Trajectory of vehicles in the 4-lane maintenance area

3.2 6-lane highway maintenance work area

The 6-lane maintenance work area is shown in Figure 5. The type of lane-changing for vehicles in the 1-lane is forced lane-changing, in which most vehicles perform a lane-changing behavior to two lanes, and a small number of vehicles to three lanes. The lane-changing type of vehicles in lane 2 is non-compulsory lane change, and a small number of vehicles perform a lane-changing behavior to lane 3.
There is no lane-changing behavior for vehicles in lane 3. Among them, the lane 1 vehicle performs the lane-changing behavior at the X-axis -150m, and completes it at the X-axis -90m, and the lane change length L is about 60m. Affected by a lane change. The lane change of the lane 2 starts at -130m on the X axis and is completed at 100m on the X axis. The lane change distance is about 30m.

3.3 8-lane highway maintenance work area

The 8-lane maintenance work area is shown in Figure 6. The lane-changing type of vehicles in lane 1 is forced lane-changing, in which most vehicles perform a lane-changing behavior to lane 2 and some vehicles to lane 3. A small number of vehicles in lane 2 change lanes to lane 3, which is an optional lane change. A few vehicles in lane 3 change lanes to lane 2, which is an optional lane change. A small number of vehicles in lane 4 change lanes to lane 3, which is an optional lane change. Lane 1 is forced to change lanes. The forced lane change starts at -95m on the X axis and ends at -40 on the X axis; the secondary lane change of lane 1 is an optional lane change and is completed at -30m on the X axis. Most vehicles start to perform forced lane changing at -145m and complete the forced lane changing at -90m. The lane change length L is approximately 55m. Lane 2 vehicles are affected by the lane change behavior in Lane 1, and some vehicles perform non-compulsory lane change behavior. The non-compulsory lane-changing behavior of vehicles in Lane 2 starts at -150m, and the non-compulsory lane-changing behavior is completed at -130m. Lane 3 is affected by the lane-changing behavior of vehicles in lane 1 and lane 2, and some vehicles perform non-compulsory lane-changing behavior. The non-compulsory lane change behavior of vehicles in lane 3 starts at -100m and completes the non-compulsory lane change behavior at -60m. Part of the vehicles in lane 4 performed non-compulsory lane change behavior. The non-compulsory lane change behavior started at -110m and completed the non-compulsory lane change behavior at -60m.

Based on the above analysis, it can be seen that with the increase in the number of lanes in the highway maintenance work area, the starting point of the forced lane change of the vehicle in lane 1 is farther away from the maintenance work area, and the end point of the lane change is similar to the six-lane and eight-lane, compared to the four-lane. The end point is further away from the work area, the lane change length L increases, and the probability of free lane change increases; the probability of free lane change in lane 2 increases, and the lane change start point is further away from the maintenance work area. The lane change end point is similar, and the lane change length L increases, the probability of lane change increases, the vehicle trajectory of the passable lanes closer to the closed lane is more concentrated, and the passable lanes farther from the closed lane are less frequently changed.

Figure 6. Trajectory of vehicles in the 8-lane maintenance area
4. Conclusions

(1) Based on the vehicle trajectory data of the highway maintenance work area based on the vehicle trajectory analysis, it is found that all vehicles in the closed lane are forced to change lanes, and the vehicles in the remaining lanes randomly change lanes, and the closer to the closed lane, the vehicles change lanes. The higher the probability, the more concentrated the vehicle trajectory.

(2) Propose the relationship between the number of lanes and the lane change distance and lane change probability. When the number of lanes increases, the lane-changing distance for forced lane changes of vehicles on closed lanes increases, and the distance between the starting point and the work area increases. The end points of forced lane-changing in six-lane and eight-lane lanes are similar, compared with four-lane forced lane change. The distance between the end point and the work area is reduced; when the number of lanes increases, the probability of free lane change of the passable lanes increases, the lane change distance increases, and the distance between the lane change start point and the work area increases, and the lane change end point is similar.

(3) This article selects the two-way four-lane, six-lane, and eight-lane road section of the expressway maintenance work area as the research object. In reality, there are still two-way ten-lane and twelve-lane expressway maintenance work areas, which are worthy of further study. Due to the huge workload, this article only studies the closed inner side of the highway maintenance work area. There are also different types of maintenance conditions such as the closed outer side of the maintenance work area, road shoulders, or reconstruction, which can be further analyzed.

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