Study of overtaking method of intelligent vehicle under vehicle road coordination

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Abstract. Aiming at the safe overtaking in the autonomous driving of the intelligent vehicle, the overtaking method of intelligent vehicle under vehicle road coordination is advanced. First, according to the current vehicle movement state and the surrounding environment, the overtaking behaviour decision is proposed. Second, with the support of vehicle-road collaboration technology, the principle of the overtaking method is analysed. The position and speed of the associated vehicles within the real-time range are collected with the Road Side Unit (RSU). The RSU communicates with the autonomous vehicle in two-way, and vehicle selects overtaking behaviour. Finally, the validity of this method is verified by the cases, the overtaking method includes overtaking in the borrowing lane, the extended overtaking lane and the emergency lane. The research results of this study not only provide a basis for the method of the safe overtaking in the process of the intelligent vehicle autonomous driving, but also lay a foundation for the intelligent transportation system (ITS).

1. Introduction

Today, vehicles with automated systems, such as adaptive cruise control, and automatic parking, are in standard production in many major vehicle companies. However, fully autonomous driving introduces challenges. One of the challenges, which has drawn much attention recently, and is the focus of this paper, is the introduction of autonomous overtaking maneuvers [1].

The intelligent vehicle with autonomous overtaking, referred to as the ego or host vehicle, is approaching a slower moving leading vehicle. In order to avoid collision with surrounding vehicles, overtaking is completed in a specific lane and then back to the original lane, which steps are as follows: 1) Detecting all obstacles and vehicles (including leading vehicles) using sensors such as light detection and ranging sensors; 2) making a decision on whether overtaking should be performed; 3) planning trajectory; 4) tracking trajectory. The division into these steps is not unique to the overtaking case but is a common way of developing autonomous features [2]. This paper studies the related work of the second step.

The safety is one of the core issues of the autonomous driving [3]. The distance between the front and rear vehicles is accurately calculated and maintained during driving. Overtaking is one of the common operating conditions of the intelligent vehicle, which consists of lane changing stage, overtaking stage and parallel lane stage [4-5]. At each stage, there may be potential accident factors from other vehicles and outside road conditions, which can easily cause safety accidents or traffic jams.
The improper overtaking could affect the driving comfort and efficiency, and is one of the important causes of traffic accidents. Therefore, the overtaking method of the intelligent vehicle are very important.

At present, with considering the restriction of related technologies, the development of intelligent transportation system (ITS) has been gradually transitioning from the single-vehicle intelligent technology to the vehicle-road cooperative technology, which can also reduce the investment cost [6-7]. Intelligent Vehicle Infrastructure Cooperative Systems (IVICS) is the latest development direction of ITS [8-9]. The advanced wireless communication, and a new generation of the internet technology is used in IVICS, which fully realizes the effective collaboration between people, vehicles and roads, so as to form a safe and efficient road traffic system [10-12].

In this paper, under the background of IVICS, the overtaking method of the intelligent vehicle under the vehicle-road coordination is studied to realize the safe overtaking of the intelligent vehicle. First, according to the current vehicle movement state and the surrounding environment, the overtaking behaviour decision is proposed. Second, with the support of vehicle-road collaboration technology, the principle of the overtaking method is analyzed. Finally, the validity of this method is verified by the cases.

2. Overtaking behaviour decision
The intelligent vehicle runs in a high-density traffic flow, and the horizontal or vertical vehicle spacing is too small to implement safe overtaking. When the vehicle runs in a low-to-medium-density traffic flow, the overtaking distance between the vehicles may be satisfied. The overtaking behavior decision is executed by the intelligent vehicles according to the current vehicle movement state and the surrounding environment. It is ensured that there is no overtaking accident during the overtaking process. The comfort of the occupant is also very necessary in the overtaking process. From the point of view of safe overtaking, the overtaking distance and the minimum safe distance of the intelligent vehicle are the basis of overtaking behavior decision, and the minimum safe distance is the safety evaluation index of the overtaking distance. Overtaking distance is divided into the transverse distance and the longitudinal distance. The transverse distance can ensure the normal driving of the vehicle in the middle of the lane. Therefore, this paper takes the longitudinal safety distance as the overtaking distance.

The speed dissatisfaction accumulation in the current state of the intelligent vehicle is as follows:

\[ A_t = \sum_{t_0}^{t_s} \frac{S_d - S(t)}{S_d} \]  

where, \( A_t \) is the speed dissatisfaction accumulation in the current sampling time interval. it is used as a reference indicator for the overtaking behavior decision. \( S_d \) is the set desired speed, in m/s. \( S(t) \) is the real-time speed in the sampling period, in m/s.

In the process of overtaking, the intelligent car makes decisions according to the safety distance, as follows:

1. When the distance of the current vehicle in the lane due to deceleration or stopping is less than the minimum safe distance (\( S_{MSD} \)), the vehicle decelerates and follows;
2. When the safety distance is satisfied, the vehicle will make the overtaking decision, and when \( A_t \) exceeds a certain value(\( A_{0t} \)), the vehicle will complete the overtaking in the safe area.

Diagram of vehicle overtaking process is shown in Figure 1.

![Figure 1. Diagram of vehicle overtaking process.](image)
The diagram of the unsafe area and the minimum safe distance for overtaking is shown in Figure 2.

![Diagram of unsafe area and minimum safe distance for overtaking](image)

**Figure 2.** Diagram of unsafe area and minimum safe distance for overtaking.

In Figure 2, vehicle M is the overtaking vehicle, and F₁ is the obstacle vehicle in the front vehicle M in the same lane, and F₂ is the obstacle vehicle in the front vehicle M in the target lane. To sum up, the overtaking behavior decision consists of the intention generation conditions and the safety conditions.

At any time \( t \), the distance between two vehicles is \( S(t) \), \( S_{MSD} \) is the minimum safe distance, \( A_0 \) is the setting value of the speed dissatisfaction accumulation. Therefore, the intention generation condition is:

\[
S(t) < S_{MSD} \text{ or } A_t \geq A_0
\]  

(2)

Safety conditions is:

\[
S_b > S_{MSD} \text{ and } S_{f_1} > S_{MSD} \text{ and } S_{f_2} > S_{MSD}
\]  

(3)

In the execution transcendence stage, the security conditions are:

\[
S_{f_1} > S_{MSD} \text{ and } S_{f_2} > S_{MSD}
\]  

(4)

When Equations (2) and (3) are both satisfied, the overtaking decision can be made and the lane change stage can be entered. Otherwise, the vehicle can only follow or brake to slow down.

The flow chart of the overtaking behavior decision is shown in Figure 3.

![Flow chart of overtaking behavior decision](image)

**Figure 3.** Flow chart of the overtaking behavior decision.
3. Principle of Overtaking Method and Case
With the support of vehicle-road collaboration technology, the intelligent vehicle can acquire the position and speed information of relevant vehicles within the distance in real time, and make real-time prediction. When the intelligent vehicle enters the overtaking lane, it adjusts its speed to ensure that it can overtake in the overtaking lane, and return to the original lane when the safety conditions is satisfied.

The overtaking lane includes the borrowing lane, the extended overtaking lane and the emergency lane. With the support of vehicle-road collaboration technology, the position and speed of the associated vehicles within the real-time range are collected with the Road Side Unit (RSU). The RSU communicates with the autonomous vehicle in two-way, and vehicle selects the overtaking behaviours.

3.1. Overtaking in the borrowing lane
When there is an opposite lane in front of the intelligent vehicle for overtaking, the RSU control unit controls its speed until it reaches the conditions for safe lane changing, and then drive to the opposite lane. When the intelligent vehicle drives in the opposite lane, the RSU control unit controls its speed and then overtake. When the safe distance is satisfied, the vehicle to return to the original driving lane, as to complete the overtaking process.

The borrowing lane overtaking refers to overtaking by occupying the opposite driving lane when driving on two-way lanes. The borrowing lanes include the opposite lane, 2+1 lane and 1.5 lane. Overtaking in the 2+1 lane refers to passing on a two-way road with extended overtaking lanes, and vehicles passing through the extended dedicated lanes. Overtaking in the 1.5 Lane overtaking refers to the use of 0.5 lanes to achieve overtaking when the vehicle is driving in 1.5 lanes.

Overtaking cases in the borrowing lane are shown in Figure 4 to Figure 7.

Figure 4. Overtaking case in the opposite lane (Inside).

Figure 5. Overtaking case in the 2+1 lane in two direction (Inside).

Figure 6. Overtaking case in the 1.5 lane in one direction (Outside).

Figure 7. Overtaking case in the 1.5 lane in one direction (Inside).

In Figure 4 to Figure 7, the lanes marked with AL are dedicated lanes for the intelligent vehicle; Unmarked lanes are the ordinary lanes suitable for the manual model vehicles; those with WIFI mark above the vehicles are the intelligent vehicles; the curve with arrows indicates the overtaking path; the lane separated by a dotted line.
3.2. Overtaking in the extended lane

When there is an extended overtaking lane in the front of the intelligent vehicle, the RSU control unit controls the speed of the vehicle and keeps it at a safe distance. When the intelligent vehicle drives to the extended overtaking lane, this vehicle changes to the extended overtaking lane, and then overtake. When the safe distance is satisfied, the vehicle to return to the original driving lane, as to complete the overtaking process.

The extended overtaking lane refers to the extended lane in the middle of the two-way driving lane, and can be shared in both directions and realized through soft isolation.

Overtaking cases in the extended overtaking lane in one direction are shown in Figure 8 and Figure 9.

![Figure 8. Overtaking case in the extended overtaking lane in one direction (outside).](image)

![Figure 9. Overtaking case in the extended overtaking lane in one direction (inside).](image)

In Figure 8 and Figure 9, the right side of the direction is indicated as the outside, while the left side of the direction is indicated as the inside.

3.3. Overtaking in the emergency lane

When there is no an extended overtaking lane in the front of the intelligent vehicle, the RSU control unit controls the speed of the vehicle until it reaches the conditions for safe lane changing, and then drive to the emergency lane. When the intelligent vehicle drives in the emergency lane, the RSU control unit controls the speed of the vehicle and then overtake. When the safe distance is satisfied, the vehicle to return to the original driving lane, as to complete the overtaking process. The overtaking position includes the inside overtaking position and the outside overtaking position. The inner overtaking position refers to the position where the rear vehicle overtakes from the left side of the driving direction; the outer overtaking position refers to the position where the rear vehicle overtakes from the right side of the driving direction.

Overtaking in the emergency lane refers to the driving vehicle uses the emergency lane to achieve overtaking when the vehicle is driving on adjacent emergency lanes.

Overtaking cases in the emergency lane in one direction are shown in Figure 10 and Figure 11.

![Figure 10. Overtaking case in the emergency lane in one direction (outside).](image)

![Figure 11. Overtaking case in the emergency lane in one direction (inside).](image)
The safety is one of the core issues of autonomous driving. The overtaking method of the intelligent vehicle under vehicle road coordination is advanced. According to the current vehicle movement state and the surrounding environment, the overtaking behaviour decision is proposed, and then with the support of vehicle-road collaboration technology, the principle of the overtaking method is analysed. The validity of this method is verified by the cases, the overtaking method includes overtaking in the borrowing lane, the extended overtaking lane and the emergency lane. Overtaking Cases include the extended overtaking lane overtaking, the borrowing lane overtaking, the 2+1 lane overtaking, the 1.5 lane overtaking, and the emergency lane overtaking. The research results of this study not only provide a basis for the method of the safe overtaking in the process of the intelligent vehicle autonomous driving, but also lay a foundation for the intelligent transportation system (ITS).

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