Speed optimal method of intelligent network vehicles passing through signalized intersection

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Abstract. Aiming at the problem that the frequent stops and changes of intelligent network vehicles passing through the signalized intersections, speed Optimal method of intelligent network vehicles passing through signalized intersection is proposed in the paper. The position and speed of the intelligent network vehicles are detected by the RSU (Road Side Unit) in real time, the distance of ahead vehicles is controlled by the method. The frequent deceleration of the vehicles passing through the signal intersection is solved effectively, at the same time reducing the vehicles fuel consumption in the running.

1. Introduction

With the continuous increase of the ownerships of car in China, the air pollution is further aggravated. When vehicles pass through the signalized intersection, frequent starting, stopping and changing speed, causing unnecessary fuel consumption [1]. Aiming at the problem that the frequent stops and changes of intelligent network vehicles passing through the signalized intersections, the speed of vehicles as the research object and improving the vehicles speed method through the signalized intersection. Real-time detection of vehicles position and speed through RSU is used to make vehicles fuel and road traffic operation efficiency [2]. The information acquisition of the intelligent network vehicles is obtained by the RSU, and the autonomous vehicles carry out two-way communication with the RSU. Finally, the optimal speed method of intelligent network vehicles can be used to increase the vehicles fuel efficiency and road traffic operation [3, 4].

2. Principle of speed optimal method of intelligent network vehicles passing through signalized intersection

There are many factors affecting the speed of cars, such as road type, ambient temperature, road congestion and the time of signal lights. The driving parameters contain vehicles speed and deceleration time. The characteristics of the vehicles include gearbox speed ratio, power system parameters, engine characteristics and so on.

The speed method of intelligent network vehicles passing through the signal intersection is shown in Figure 1. The car starts at point A and ends at point B. AB represents the distance between the car and the traffic light. The network vehicles and the traffic light can realize real-time communication through the RSU. When the vehicles is running normally, the current status information of the signal light, the current speed of the vehicles and other ahead vehicles information can be obtained. So, the speed trajectories between AB can be planned out.
Figure 1. The speed optimal method schematic diagram.

Making the vehicles drive at a constant speed is the purpose of the speed Optimal method of intelligent network vehicles passing through the signalized intersection. According to the Reference [5], when the vehicles speed is 40km/h-50km/h, the fuel consumption of the vehicles can be used in the minimum. The fitting results of speed and fuel consumption can be obtained from the fitting data in the Reference [6], the Equation (1) as follows.

\[ H_c = \alpha v^3 + \beta v^2 + \psi v + C \]  

(1)

where, \( H_c \) is instantaneous fuel consumption, \( v_0 \) is the optimal recommended speed, \( \alpha, \beta, \psi, \gamma \) are the proportional coefficient of different kinds of vehicles. The flow chart can be obtained as shown in Figure 2.

Figure 2. The flow chart of the speed optimal method.

Unnecessary fuel consumption is caused by adjusting the proportion of acceleration and deceleration of vehicles, when they passing through the signalized intersection [7]. The information of intelligent network vehicles is obtained with the vehicles-road coordination technology of RSU. RSU and intelligent network vehicles conduct two-way communication. The acquisition and required variables of intelligent network vehicles are shown in Table 1.
Table 1. The acquisition and required variables of intelligent network vehicles.

| Variable | Meaning | Real-time Parameter | RSU Parameter |
|----------|---------|---------------------|---------------|
| $v_c$    | start speed | ✓ | ✓ |
| $v_r$    | recommend speed | ✓ | |
| $v_{\text{max}}$ | road limit speed | ✓ | ✓ |
| $a_1$    | feed acceleration | | |
| $a_2$    | reduce acceleration | | |
| $v_0$    | optimal recommended speed | ✓ | ✓ |
| $l_c$    | current position of vehicles | ✓ | ✓ |
| $s_c$    | current traffic light status | ✓ | ✓ |
| $s$      | distance to signalized intersection | ✓ | ✓ |
| $t_{\text{max}}$ | maximum travel time | ✓ | ✓ |
| $t_{\text{gr}}$ | current green remaining time | ✓ | ✓ |
| $s_a$    | total distance between all leading vehicles and the signal light | ✓ | ✓ |
| $v_{\text{se}}$ | the speed of accelerating from the beginning to the end | ✓ | ✓ |
| $t_{\text{se}}$ | the time required to travel uniformly to the destination | ✓ | ✓ |
| $t_a$    | the time required to increase or decrease the starting speed $v_c$ to the optimal speed $v_0$, and then to travel at a uniform speed $v_0$ to the end point | ✓ | ✓ |

3. Application of speed optimal method for intelligent network vehicles passing through signalized intersections

3.1. Determination of variables of speed optimal method for intelligent network vehicles passing through signalized intersections

The starting and stopping of trucks consumes the most fuel, so the starting and stopping of trucks are used as an example. Proportional coefficients are as follows. $\alpha=0.00003$, $\beta=0.001$, $\psi=-0.0986$, $C=8.455$. From the above parameters, when $v_0=43.036$, the minimum value of $H_c$ is 5.9348, that is, when the speed is 43.036km/h, the minimum fuel consumption is 5.9348L/100km.

To make the vehicles fuel consumption as small as possible, as far as possible to make the vehicles driving in the uniform state [8], when acceleration $a_1=2.5$ m/s$^2$, $a_2=-2.5$ m/s$^2$, passengers aboard experience is best, so the follow-up recommended rate of $v_r$, using the acceleration into, but the reference does not take into account all the preceding vehicles from the intersection of the total distance $s_a$, it will cause traffic accidents because of calculation errors. Below, the recommended speed $v_r$ under different conditions is solved. The quantitative parameters of intelligent network car are summarized as shown in Table 2.

Table 2. The quantitative parameters of intelligent network car.

| Variable | Values | Unit |
|----------|--------|------|
| $\alpha$ | 0.00003 | /    |
| $\beta$  | 0.001  | /    |
| $\psi$   | -0.0986 | /    |
| $C$      | 8.455  | /    |
| $v_0$    | 43.036 | km/h |
| $a_1$    | 2.5    | m/s$^2$ |
| $a_2$    | -2.5   | m/s$^2$ |
3.2. Example of speed optimal method for intelligent network vehicles passing through signalized intersections

The speed of accelerating from the beginning to the end is \( v_{se} \), the Equation (2) as follows.

\[
2 \frac{1}{a} = v_{max}^2 \cdot \frac{s - s_a}{v_c} + \frac{v_c}{a} \cdot \frac{v_c}{a} - v_c^2 + (s - s_a) \cdot \frac{v_c^2}{v_{max}^2 - v_c^2} \cdot (2a_1v_{max})_{max}, \quad v_{se} < v_{max}
\]

The minimum time from the start to the end as follows.

\[
t_{min} = \begin{cases} 
(s - s_a) / v_{max}, & v_{se} = v_{max} \\
\frac{v_{me} - v_c}{a}, & v_{se} < v_{max} \\
\frac{(v_{max} - v_c)}{a} + (s - s_a) / v_{max} - (v_{max}^2 - v_c^2) / (2a_1v_{max}^2), & v_{se} > v_{max}
\end{cases}
\]

The time required to travel from the starting speed to the end as follows.

\[
t_{se} = \frac{s - s_a}{v_c}
\]

The time required to accelerate or slow down to the current speed at the starting speed, and then drive uniformly to the end as follows.

\[
t_e = \frac{v_r - v_c}{a} + \frac{(s - s_a)}{v_r} - \frac{v_r}{2a} - \frac{v_r^2}{2av_r}
\]

To solve the recommended speed \( v_r \) that is under different signal states and different initial speeds. The solving process is divided into green light state and red light state.

1) Green light state

When green light time is enough, the vehicles can pass the current green time; when the vehicles cannot pass the current green with less time left, let the vehicles pass the signal when the next red light turns green. The recommended speed under green light is divided into the following two situations:

a) When \( t_{max} < t_{gr} \), the vehicles can pass the signal at the current green time. Meanwhile, when \( t_g \leq t_{gr} \), at this time, the optimal speed \( v_0 \) is used; otherwise, the maximum travel time \( t_{gr} \) is used to obtain Equation (6):

\[
t_{gr} = \frac{v_r - v_c}{a} + \frac{(s - s_a)}{v_r} - \frac{v_r}{2a} - \frac{v_r^2}{2av_r}
\]

where, \( t_{gr} \) is the remaining time of the current green light. According to Equation (6), the speed \( v_r \) as follows.

\[
v_r = \begin{cases} 
v_0, & t_g < t_{gr} \\
v_c + a_1t_{gr} - a_1t_{gr} \cdot \frac{a_1^2t_{gr}^2 + 2a_1(s - s_a) - 2a_1v_c t_{gr}}{2a_1v_c}, & v_g > v_c, t_g > t_{gr} \\
v_c + a_2t_{gr} + \sqrt{a_2^2t_{gr}^2 + 2a_2(s - s_a) - 2a_2v_c t_{gr}}, & v_g < v_c, t_g > t_{gr}
\end{cases}
\]

Equation (7) shows that when the vehicles can pass the current green light at the optimal speed \( v_0 \), then the optimal speed \( v_0 \) is used. If the green light cannot be passed at the optimal speed, a recommended speed \( v_r \) can be calculated to make the vehicles pass the green light smoothly without violating traffic rules.

b) When \( t_{max} > t_{gr} \), the vehicles cannot pass at the current green time and needs to pass the signal at the next green time. When \( t_g \geq t_{gr} + 20 \), then the optimal speed \( v_0 \) is used; otherwise, the Expression (8) can be obtained by using the shortest time \( t_{gr} + 20 \):

\[
t_{gr} + 20 = \frac{v_r - v_c}{a} + \frac{(s - s_a)}{v_r} - \frac{v_r}{2a} - \frac{v_r^2}{2av_r}
\]

where, \( t_{gr} \) is the remaining time of the green light. According to Formula (8), the recommended speed \( v_r \) as follows.


among them:

\[ v_{r1} = v_c + a_2 (t_{gr} + 20) + \sqrt{a_2^2 (t_{gr} + 20)^2 + 2a_3 (s - s_a) - 2a_3 v_c (t_{gr} + 20)} \] (10)

\[ v_{r2} = v_c + a_4 (t_{gr} + 20) - \sqrt{a_4^2 (t_{gr} + 20)^2 + 2a_4 (s - s_a) - 2a_4 v_c (t_{gr} - 20)} \] (11)

At this point, all of the recommended speeds for the green light case have been found. Next, we will solve for the recommended speed in the case of red light.

(2) Red light state

When the remaining time of the red light is short and the vehicles can pass the signal light at the optimal speed of \( v_0 \) without stopping, the travel time is \( t_g \). When the remaining time of the red light is long and the \( v_0 \) cannot pass the signal light at the optimal speed, a recommended speed \( v_r \) is calculated according to the starting speed, the signal light state and the signal light distance to make the vehicles pass the signal light when the red light turns green. At this time, the travel time is \( t_r \). According to the travel time, the following expression can be obtained as follows.

\[ t_r = \frac{v_r - v_c}{a} + \frac{(s - s_a)}{v_r} - \frac{v_r^2}{2a} - \frac{v_c^2}{2a} \] (12)

where, \( t_r \) is the remaining time of the current red light. According to Equation (12), the recommended speed \( v_r \) as follows.

\[ v_r = \begin{cases} 
  v_{0r} & v_0 < v_c, t_g \geq t_r \\
  v_c + a_1 t_r - \sqrt{a_1^2 t_r^2 + 2a_1 (s - s_a) - 2a_1 v_c t_r} & v_0 > v_c, t_g < t_r, t_{se} > t_r \\
  v_c + a_2 t_r - \sqrt{a_2^2 t_r^2 + 2a_2 (s - s_a) - 2a_2 v_c t_r} & v_0 > v_c, t_g < t_r, t_{se} < t_r \\
  v_c + a_3 t_r - \sqrt{a_3^2 t_r^2 + 2a_3 (s - s_a) - 2a_3 v_c t_r} & v_0 < v_c, t_g < t_r \\
  \end{cases} \] (13)

At this point, all cases of the semaphore at different starting states have been considered, and the recommended speed in all cases has been calculated.

4. Conclusions

A speed optimal method of intelligent network vehicles passing through signalized intersection is proposed in this paper, which can help vehicles to pass the signal intersection without stopping, and reduce fuel consumption. The method provides a speed optimized trajectory for vehicles, which can avoid frequent stops and starts in the process of driving, and effectively reduce the accident rate by considering the situation of existing vehicles in front.

Although some achievements have been made in the algorithm design, there are still some problems and shortcomings. First of all, deep learning has an amazing performance in big data processing, which can be used to predict the behavior of vehicles, so as to reduce the fuel consumption. Secondly, the data in this paper is not comprehensive enough, the coverage of data is not enough, when the database can be enriched, the effect will be better; In addition, the proposed speed optimal method only considers the behavior of one object, but the actual road conditions are very complex.

At present, deep learning processing function is characterized by independent data feature extracting, from input to output without human intervention, the process can be thought of as an end-to-end black-box operation, can effectively reduce the manpower, if can predict closely integrated with the vehicles, the vehicles safety and intelligent driving will be a huge boost role [9, 10].
Acknowledgement
This work was supported by Major Open Fund Projects from Foshan Xianhu Laboratory of the Advanced Energy Science and Technology Guangdong Laboratory (XHD2020-003).

References
[1] Li Shengbo, Xu Shaobing, Wang Wenjun and Cheng Bo 2014 Overview of economical driving technology and application of automobile[J]. Journal of Automotive Safety and Energy Conservation 2(13) 987-990
[2] An Shi, Yao Handong, Jiang Huifu and Cui Jianxun 2015 Green driving speed control method at signalized intersection[J]. Transportation System Engineering and Information 5(9) 143-165
[3] Zhang Baocun, Ran Bing, Mei Chaohui and Zhang Peiling 2013 Optimization method of signal control at road intersections under vehicle-road coordination[J]. Transportation System Engineering and Information 12(7) 596-597
[4] Huang Kun, Liu Xingliang, Wu Yimin and Zhu Shihao 2010 Research on vehicle following and lane changing model based on multi-vehicle information[J]. Automotive Technology 10(19) 1352-1354
[5] Wang Jinghui and Rakha Hesham A 2016 Fuel Consumption Model for Conventional Diesel Buses[J]. Applied Energy 170(3) 394-399
[6] Wei Tao 2019 Research on energy-saving driving behavior and speed Optimal methods in networked vehicles environment[D]. Chang’an University
[7] Zhang Feng and Chen Xingxing 2019 Driving behavior based on data of Internet of vehicles - a study on speed control[J]. Journal of Yangtze University 16(11) 126-130
[8] Grzegorz Iwanski, Łukasz Bigorajski and Włodzimierz Koczara 2018 Speed control with incremental algorithm of minimum fuel consumption tracking for variable speed diesel generator[J]. Energy Conversion and Management 15(12) 184-186
[9] Yao Baozhen, Chen Chao and Cao Qingda 2016 Short-Term Traffic Speed Prediction for an Urban Corridor[J]. Computer-aided Civil and Infrastructure Engineering 6(9) 1165-1183
[10] Wang Jingyuan, Li Chao, Xiong Zhang and Shan Zhiguang 2014 A review of data-centric smart city research[J]. Computer Research and Development 51(2) 239-259