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Novel algorithm of traffic signals adaptive control on urban roads intersections

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Abstract: The control of traffic flows on urban roads intersections through the traffic control signals is very important, not only does the jammed traffic statement valuably relieve and the ratio of the traffic availability increase, but also the traffic accidents evidently decrease. In this paper, an adaptive algorithm of traffic control signals on the urban roads intersections is designed in , this new algorithm can actively adjust the concrete control times of the traffic control signals based on the perceiving information of the waiting vehicles in real time, then the dynamic balance between the traffic control signals and the traffic flows can be realized. Furthermore, through experiment testing and demonstrating, this adaptive algorithm expresses some fine performances, it also shows good application prospect in the field of smart city.

Keywords: Traffic engineering; Urban road intersections; Traffic control signals; Perception devices; Adaptive algorithm; Control phases.

1 Introduction

In urban areas, roads on ground always have many intersections with different directions which become the conflict of traffic flows, in order to pass through the intersection with safety, order, and high availability, the vehicles must be guided, separated and controlled near the intersection. Traditionally, traffic control signals which are installed on the intersection of urban roads can make key roles of separating vehicles and avoiding traffic conflicts. Generally, in the same moment, the traffic control signals permit two directions which are opposite each other traffic flows to pass through the intersection, and the rest traffic flows with other directions are forbidden to pass through the intersection simultaneously, that is the rest traffic flows are stopping to queue.

The operation of the traditional traffic control signals takes some defects, there are some typical cases, the most ordinary situation is that the vehicles make long queue up on one side because the control time which the traffic tools are allowed to pass through the intersection at the direction is too short, on the contrast, there are no traffic tools on one side road because the control time which the vehicles are allowed to pass through the intersection is too long, and many traffic tools which are from other side directions of the intersection have to make queue up too. Those situations may lead to decrease the traffic availability and postpone the driving time of the drivers and passengers. To analyze the defects of the existing traffic signals control technologies, the main problem is that the control times of the traffic control signals are ordinarily static after the systems of the traffic control signals are installed, so the control times can not reflect the performance of the change of the traffic flows on the roads near the intersection, this factor becomes a reason to make some traffic accidents.

There existed some documents to study the optimization of the traffic control signal system, in document [1], optimization method of continuous light control on intersections was studied, in document [2], stochastic optimization framework for road traffic controls was pointed out, in documents [3-6], the optimization methods with advanced IT are analyzed, in document [7], a sub-optimal algorithm based on the idea of adaptive equalization was discussed, in documents [8-12], some relevant technologies of the traffic control signals are analyzed, and so on.

In this paper, based on the analysis of the characters of the traffic flows and operational principles of the traffic control signals, a of adaptive control is pointed out, the key idea of this adaptive algorithm is that the change of the traffic control signals matches up the change of the traffic flows in real time, the traffic availability can increase and the ratio of the traffic accidents decreases.

2 Analysis of the traffic flow characters and the traffic signals operational principles on a road intersection

The traffic flows that are near urban roads intersection have some particular properties, these properties can be summed up the following points: one is that the road intersection is a junction of the different directions of different traffic flows, so some traffic flows are variable, not only do the velocities of it change, but the concrete directions of it change, then the continuous flow changes to be interrupted, so the continuous traffic flow becomes discrete traffic flow. Two is that the traffic flows which are on near the intersection have the properties of randomicity and periodicity, within a long duration, the traffic flows express the periodic phenomena, but as to the concrete properties, such as the length of the queuing traffic flow, are random at due time.

Furthermore, the traffic flows are concerning with the concrete spatial shape of the intersection. Generally, the shape of the intersection is trinacriform (three-fork) or *x*-form shape (four-fork), so if the traffic control signals are not be equipped and make effect,

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then the traffic flows which are from different directions will come to a clash on the same time. So the traffic control signals are designed to make controls to decide the different traffic flows to be the passing statement or the stopping statement. Based on the laws of urban road traffic and intersection shape, the traffic flows with driving on right on near the intersection at same time are concluded as follows of Fig. 1 and Fig. 2.

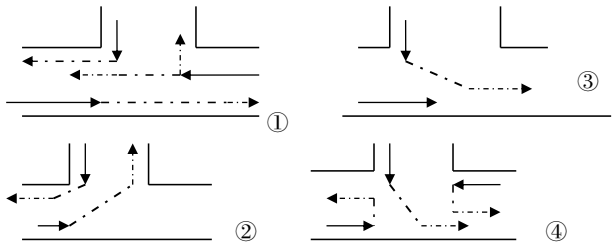

Fig. 1 All possible statements of traffic flow in three-way intersection.

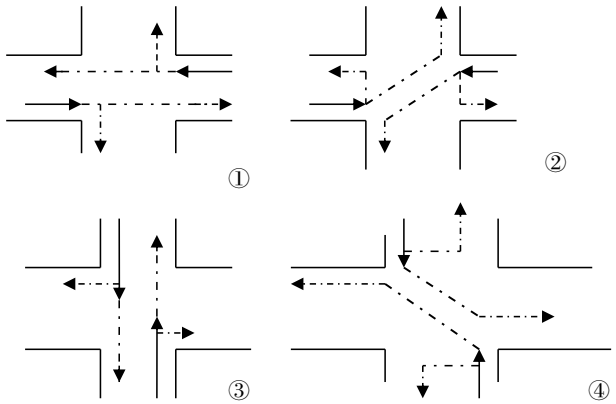

Fig. 2 All possible statements of traffic flow in four-way intersection.

Based on the performances of traffic flows on the near sides of the intersection, then the whole working of the traffic control signals can be regarded as the repeat of the period T which the signals are working in a completely turn, further, a period T also can be divided into some different processes, in one process expresses, are only a pair traffic flows with the counter-direction each other are permitted to be passing the intersection, the other traffic flows with other directions have to be the stopping statement, then, a process of the whole period T is denoted a phase. Then if a whole period T is divided into n ($n \geqslant 2$) processes, and every process is decided to maintain t_i ($1 \leqslant i \leqslant n$) duration time, the period T is denoted as Eq. (1):

$$T = \sum_{i=1}^{n} t_i. \tag{1}$$

Based on the above analysis, the traffic control signals working principles are restricted by two key elements: one is n that expresses the number of the phases in a whole period, another is the duration time of every phase. n is influenced by the shape of the intersection, and the duration time of a phase is influenced by the traffic flow queues in real time.

3 Analysis the principle of this novel method

Traditionally, the period T and duration time of the traffic signals control were prior designed in and constant, then the working rhythms of traffic signals do not adapt to the changeable rhythms of the traffic flows in real time, so there will appear two extreme phenomena, one phenomenon is that the control signal expresses the 'passing' statement, but there are no traffic tools to pass the intersection, the road is in idle condition, then the traffic efficiency decreases, another phenomenon is that there are many traffic tools to wait for passing the intersection and to become a long length queue, which dues to taking place traffic accident, this phenomenon becomes a reason to decrease the traffic efficiency on near the intersection roads, it also brings about the drivers dispiriting.

In order to overcome the above defects of the traditional traffic signals control on urban roads intersection, the is designed in, the main creative point of this algorithm is that the working rhythms of the traffic control signals are adaptive to the changes of the traffic flow in real time, that is the duration time of every phase adapts to the time of the waiting queue of the traffic tools, besides, the period T also adapts to the time of a whole turn of the traffic tools change. Then in generally, the algorithm can be described as follows: based on the recognition of the traffic tools on the roads near the intersection with video signal or other perceiving signals modes, the duration passing time of the passing traffic flow, which adapts to the real traffic flow, are estimated, then two extreme phenomena of decreasing traffic efficiency can be avoided.

The concrete realization of this is divided into three steps. At first, near the intersection, some perception devices have been equipped and these devices can offer fine sensing information. Secondly, based on the shapes of the intersection, the working phases which decide the passing statement or stopping statement of the different traffic flows by the traffic control signals are decided prior, the parameter n is decided too. Thirdly, the duration time of phase when one direction of the traffic tools is permitted to pass the intersection is concretely calculated.

To presume the traffic control signals to change the passing traffic flow on the moment T_0, then on the direction which the queuing traffic tools will change the statement from the stopping to passing, the queuing length is perceived by the perception devices, if the queuing length is $l_{\max}$, the vehicles which are queuing within the length l ($l < l_{\max}$)are asked to pass the intersection in this phase, and also v_0 is presumed the average velocity of passing the intersection, $t_{i,1}$ is presumed the average time from the startover of the first vehicle to startover of all waiting vehicles in the queue, $t_{i,3}$ is presumed the time of the last vehicle which is permitted to pass the intersection during this phase, $t_{i,1}$ and $t_{i,3}$ can be decided through statistical analyzing the history record data of the intersection. Then duration time of this passing statement is denoted Eq. (2):

$$t_i = t_{i,1} + t_{i,2} + t_{i,3}. \tag{2}$$

Here, $t_{i,2}$ is decided by Eq. (3):

$$t_{i,2} = l / v_0. \tag{3}$$

Furthermore, Eq. (1) is rewritten as Eq. (4):

$$T = \sum_{i=1}^{n} t_{i,1} + t_{i,2} + t_{i,3}. \tag{4}$$

Then the operational time t of the traffic control signals can be described as Eq. (5):

$$t = T_0 + mT = T_0 + m\left(\sum_{i=1}^{n} t_{i,1} + t_{i,2} + t_{i,3}\right). \tag{5}$$

Here, parameter m is the period number of the operating traffic control signals.

Because the duration time of different phases of the traffic control signals is dynamic and adaptive to the change of the real traffic flow, so not only the duration time but also the period T does become variables, they can accurately reflect the change of the traffic flows in real time. Furthermore, if the perception devices perceive no vehicles to make queue in the coming passing phase, then the duration time of the next passing statement becomes zero, that is the phase of passing statement will jump to the next phase. And so on.

Fig. 3 is a summary of this adaptive algorithm.

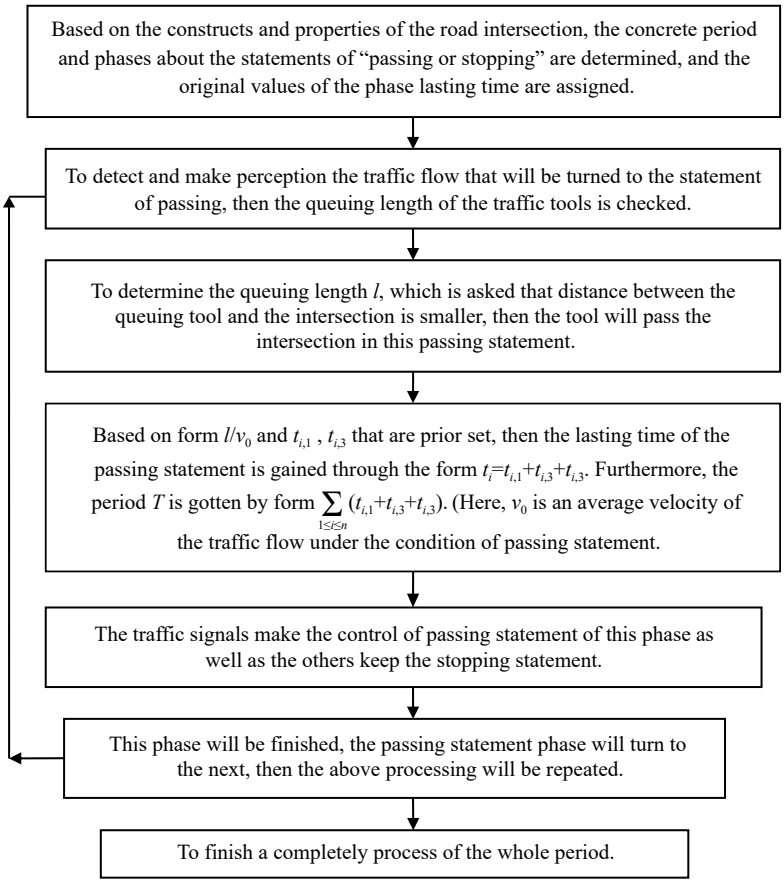

Fig. 3 The diagrammatic sketch of this adaptive algorithm.

4 Realization and test performance analysis

As to now, the technologies of perception and computing have rapidly developed, some advanced technologies of them have been applied successively in traffic field, especially, some algorithms that focus on the domain of the intelligent traffic system also have appeared along with the developing the AI, so the complex computing problem and others had no longer become the obstacles of the novel technologies application. So the perceiving and computing technologies can support completely this adaptive algorithm to be realized. Furthermore, this algorithm is regarded as a part of the urban intelligent traffic system (ITS).

In order to test the advantages of this adaptive algorithm, an experiment was made. In this experiment, the performances of road availability and postponing time are considered, the testing results of the novel adaptive algorithm are compared with the testing results of the const time control method, then Fig. 4 and Fig. 5 are gained.

Based on the results of the concrete test, it is clear that this adaptive algorithm can really increase the traffic availability and efficiency, besides this, the phenomena of the long queuing and no

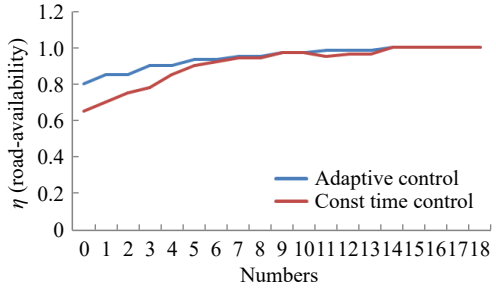

Fig. 4 Ratio of the road availability.

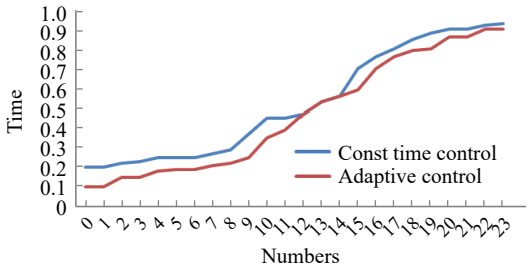

Fig. 5 Postponing time of the vehicle.

vehicles waiting no longer show up, then it also decreases the postponing time of the vehicles that passed through the road intersection.

5 Conclusion

This novel adaptive algorithm is based on the advanced intelligent technologies on traffic fields, then the traffic control signals can dynamic adapt to the change of the traffic flows in the real time, some extreme phenomena of decreasing traffic efficiency and breeding traffic accidents can be effectively avoided. The test results demonstrated that this adaptive algorithm is really valuable.

Furthermore, with the continuous developing of the cognitive technologies and the analytical technologies, the performances of this will express more outstanding, this algorithm will have a very broad development application prospects in the future.

Declaration of competing interest

The authors have no competing interests to declare that are rel-

evant to the content of this article.

Data Availability Statement

Some or all Data, models, or code that support the findings of available from the corresponding author upon reasonable request.

References

[1] Liu XX. Research on the traffic organization optimization method of continuous light control on intersections. Smart City, 2019, 5(9): 87−88.

[2] Jin JC, Ma XL, Guo HF. A generalized and stochastic optimization framework for road traffic controls. Processing of the 13thITS. Tianjin, China: 2018.

[3] Wang YP, Guo G. Joint optimization of vehicle speed and traffic signals at a signalized intersection. Control and Decision, 2019: 2397−2406.

[4] Li GL. The research and system design of urban traffic signals control based on the forecast of traffic flow. Guangzhou: South China of Technology, 2018.

[5] Shu LZ. Research on urban road traffic control algorithm based on deep learning theorem. Chengdu: University of Electric Science And Technology Of China, 2020.

[6] Davis LC. Journal of controlling traffic flow near the transition to the synchronous flow phase. Physica A: Statistical Mechanics and its Applications, 2006, 368(2): 541−550.

[7] Zhang HJ. A novel method of traffic lights adaptive control on the urban road intersections. Proceedings of the 2015 4th International Conference on Computer, Mechatronics, Control and Electronic Engineering. Guangzhou: Atlantis Press, 2015. https://doi.org/10.2991/iccmcee-15.2015.69.

[8] Jiang R, Jia B, Wu QS. The stochastic randomization effect in the on-ramp system: single-lane main road and two-lane main road situations. Journal of Physics A: Mathematical and General, 2003, 36(47): 11713–11723.

[9] Zhao X, Gao Z. Controlling traffic jams by a feedback signal. The European Physical Journal B - Condensed Matter and Complex Systems, 2005, 43(4): 565–572.

[10] Helbing D, Tilch B. Generalized force model of traffic dynamics. Physical Review E, 1998, 58(1): 133−138.

[11] Transportation Research Board. Highway capacity manual. Beijing: China Communications Press Co., Ltd, 2007: 75−91.

[12] Zhang HJ. Some novel development of ITS. Beijing: China Communications Press Co., Ltd, 2015: 80−123.