Design and Optimization of Urban Signal Fuzzy Controller Based on IQPSO

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Keywords: Traffic Signal, Fuzzy Control; Improved Quantum Particle Swarm Optimization (IQPSO);

Abstract. In order to overcome the shortcomings of traffic signal fixed-time control method, a fuzzy control algorithm for urban traffic signal is proposed. The signal phase switching order is adjustable. The improved quantum particle swarm optimization(QPSo) is also introduced to optimize fuzzy control rules of traffic signal controller. Take four-phase traffic signal commonly used in current practice for example. Compared with traffic signal fixed-time control and single fuzzy control method, the control method put forward in this paper can reduce the vehicles’ average delay time in junction. The simulation results show that the proposed algorithm is proved to be an effective and practicable method for urban traffic self-adaptive control.

Introduction

Urban transport is an important part of the urban construction and development. The effective control of intersection traffic signal is the basis of orderly functioning of urban traffic. Currently, there are three main traffic signal control methods: fixed-time control[1], half-induction control and full-induction control[2].The first traffic signal control method is simple and easy to implement; however, this method cannot adjust the operating parameters of traffic signal according to junction traffic volume. The disadvantage of last two control methods is low utilization of signal green time, which led to its limited application.

Through the study of the urban intersection traffic flow, it is found that intersection traffic flow has strong uncertainty and randomness, so the controlled junction cannot be modeled precisely in mathematically. The fuzzy control is a non-model control method, which does not need to establish accurate mathematical model of the controlled object and can also describe the qualitative model of complex systems well; thus, scholars inboard and abroad proposed that fuzzy logic can be introduced into the field of signal control. In 1977, Pappis and Mamdani [3] described a fuzzy logic controller for a single traffic junction of two one-way streets, the simulation results showed that the fuzzy control method could reduce vehicle average delay time by 7% than traditional fixed-time control. Domestic scholars Chen Hong[4], applied fuzzy control to a multiphase intersection successfully. Overall, domestic and foreign scholars’ research on traffic signal fuzzy control are mainly focused on two areas: 1) The design of traffic signal fuzzy controller structure [5,6]. Multilevel fuzzy controller structure is adopted to enhance the system scalability. 2) Combine traffic signal fuzzy control with artificial intelligence(AI) algorithm[7,8,9]. AI algorithm is adopted to optimize the signal controller parameters to achieve adaptive control.

Design of Traffic signal Fuzzy Controller

In this paper, the input variables of traffic controller are QG and QR. QG represents the number of queuing vehicles in green phase and QR corresponds to the number of queuing vehicles in red phases. Output variable, T, is delay time of green signal. Minimum green time is generally set to be 15 seconds and maximum green time set to be 90 seconds.
The range of input variable, QG, is \([0,30]\) (unit: pcu/lane), setting its domain as \(W\), \(W=\{0,1,2,3,4,5,6,7,8,9,10,11,12\}\). The fuzzy subset of QG is divided into seven linguistic values: very little, little, less, medium, more, many, very many, respectively expressed as VF, F, FP, C, MP, M, VM; the other input variable, QR, holds the same domain and linguistic values with QG. The range of output variable, T, is \([15,90]\), setting its domain as \(V\), \(V=W\). The fuzzy subset of T is divided into seven linguistic values: very short, shorter, short, medium, longer, long, very long, respectively expressed as VS, S, SP, C, LP, L, VL. Since the time control precision for the traffic signal is not very high, a simple triangular membership function is used to input and output variables. According to the experts’ controlled experience [7], the traffic signal control rules are concluded in Table 1.

**Table 1 Fuzzy Control Rule Table**

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**Traffic Signal Intelligent Control Algorithm**

When the traffic distribution at the junction is uneven in green phase, it will cause few or even no vehicles through junction; however, the vehicles in red phase are still waiting to cross. This situation will cause green time loss. In order to solve this problem, traffic signal fuzzy control algorithm based on phase sequence switching is put forward. The algorithm process is described as follows.

**Step1.** Select the initial green phase and determine minimum green time \(G_{\min}\), maximum green time \(G_{\max}\), and amber time of each phase.

**Step2.** Assign minimum green time to the current green phase \(i=4, 3, 2, 1\). Obtain the number of vehicles QG and QR measured by vehicle detector over \(G_{\min}\) seconds in junction.

**Step3.** Both QG and QR are input into traffic signal fuzzy controller then the output, green extension time \(\Delta G\) is obtained. If \(G_{\max} \geq \Delta G + G_{\min}\), \(G_{\max} - G_{\min} = \Delta G\). After fuzzy reasoning, the total green time of current green phase is \(G_i = G_{\min} + \Delta G\).

**Step4.** Assuming that the lapse of current green phase time is \(G_{\text{pass}}\), when \(G_{\text{pass}} > G_{\min}\), the rest of green time is \(G_{\text{rest}} = G_i - G_{\text{pass}}\). If \(G_{\text{rest}} \geq \lambda\) (\(\lambda\): phase switching threshold), continue the current green phase; otherwise, switch to next phase whose phase urgency for green time is most. In order to prevent signal phase from switching frequently, selecting a reasonable value of \(\lambda\) is necessary. In general, \(\lambda\) should not be more than 10. If \(G_{\text{rest}} = 0\), return to step 2 and switch to next phase.

**Step5.** Based on data measured by vehicle detector, judge whether any vehicle is waiting for crossing junction in non-critical traffic direction; if so, return to Step4; otherwise, switch to next phase and return to Step1.

**Optimization of Control Rules Based on IQPSO**

Transportation system is complex and easy to be influenced by random factors; thus control rules should be adjusted accordingly when traffic volumes in junction fluctuate. In order to achieve this goal, improved quantum particle swarm (IPSO) algorithm [8,9] is adopted in this paper to optimize fuzzy rules of traffic signal controller dynamically.

Particle swarm optimization (PSO) algorithm is developed by Kennedy and Eberhart in the late 90s [10]. Inspired by the basic theory of quantum physics, Professor Sun et al. [11] studied the
individual practice moving in a quantum style and proposed quantum-behaved particle swarm optimization algorithm (QPSO). Compared with standard PSO algorithm, QPSO has such advantages as simpler evolution equations and less control parameters. The equations that particles in QPSO update its position is listed in [11]. Like standard PSO, the search performance of QPSO largely depends on the choice of initial parameters, which is easy to fall into local optimum. In order to improve the accuracy of QPSO algorithm and convergence speed, an improved QPSO algorithm with mutation operation and orthogonal initialization is presented.

a. Orthogonal initialization

Before solving an optimization problem, the optimal solution of the problem is usually unknown. If initial population is generated randomly, individuals may not be representative. If particles distribute in the feasible region as much as possible during initial process, the algorithm will be able to search in the entire feasible space. Inspired by this idea, orthogonal initialization strategy is introduced into QPSO algorithm.

During orthogonal initialization, a = (a₁, a₂, ..., a_n) is considered as a particle. ai represents ith factor of particle a. ai, (ai ∈ [lᵢ, uᵢ]) is quantified as bi = (b₁, b₂, ..., b_Q), where bj is determined by Eq. 1.

\[
    b_{j} = \begin{cases} 
    l_{i}, & j = 1 \\
    l_{i} + (j-1)^{a} \left( \frac{u_{i} - l_{i}}{Q-1} \right), & 2 \leq j \leq Q-1 \\
    u_{i}, & j = Q 
    \end{cases}
\]

(1)

where bj represents the jth level of the ith factor, li and ui are the upper and lower bounds respectively. Orthogonal initialization ensures that the initial populations are distributed throughout the feasible region evenly.

b. Mutation

Like standard PSO algorithm, QPSO algorithm also has flaw such as prematurity. In order to solve this problem, mutation operator is introduced to increase the diversity of the population and prevent population from pre-maturing. Assuming that the probability of mutation is pm, generating a random number r between 0 and 1 for each particle respectively, if pm < r, update the corresponding particle’s position vector.

Simulation and Analysis

In order to simulate the actual extent of the traffic congestion at the crossing, the random numbers obeying the binomial distribution are used to describe the traffic flow. Fuzzy control method with IQPSO optimization is compared with fixed-time control method and fuzzy control means without any optimization method. The average delay of vehicles is used as the evaluation criterion. The simulation results are showed in Fig.1 and Fig.2.
By analyzing the performance of the above three algorithms in the aspect of reducing the vehicles’ waiting time, we can conclude that:

i. As can be seen from Fig.1, during [0,2000], the above three control modes differ little from the average vehicle delay; however, with traffic in junction increasing during [2000,6000], the average delay time under fixed-time control mode gradually increases. Therefore, the fixed-time control method cannot deal with traffic situations like traffic jam condition. Once congestion occurs, if vehicles are not mitigated timely, a great degree of congestion will happen.

ii. As can be seen from Fig.1, compared with fixed-time control mode, fuzzy control mode has better performance in reducing vehicles’ waiting time.

iii. As can be seen from Fig.2, compared with fuzzy control mode without any optimization, the fuzzy control mode with IQPSO optimization can further reduce the average vehicle delay time and have better regulation.

Summary

This paper proposed an intelligent traffic signal fuzzy control algorithm based on improved quantum particle swarm (IQPSO). Simulation results show that the traffic signal fuzzy controller with IQPSO optimization is better than fixed-time control mode and fuzzy control without optimization. It causes less vehicles delay time and is feasible for the actual intersection traffic control. However, the signal control algorithm put forward in this paper only focus on isolated intersection now; thus, further research will be focused on extending this adaptive control algorithm to several adjacent intersections among road network.

References

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10.4028/www.scientific.net/AMM.527.152