Signal Adaptive Control of Isolated Intersection Based on Type-Two Fuzzy Control

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Abstract. In this paper, the signal control problem of isolated intersection during peak period is studied based on the type-two fuzzy control method to reduce the vehicle delay of isolated intersection. Firstly, the traffic flow model and evaluation index model of isolated intersection are established, and the factors of saturation flow rate and lane length are fully considered. In order to relieve the traffic pressure effectively, a type-two fuzzy controller is proposed for the signal control method, which solves the coordination and dynamic uncertainty problems in the traffic of isolated intersection. By using adaptive genetic algorithm to optimize the parameters of membership function in the type-two fuzzy controller, the parameters of the type-two fuzzy controller can be adjusted in real time according to the change of traffic flow, so that the controller can achieve adaptive control effect of traffic signals. At last, the simulation results show that the type-two fuzzy controller designed in this chapter has a better control effect in the peak period of traffic flow and reduces the vehicle delay of isolated intersection.

1 Establishment of four phase isolated intersection model

In the field of traffic control, the study of signal control algorithms at isolated intersections is the basis [¹]. In recent years, the development of artificial intelligence technology is getting faster and faster, so the research on the intelligent control methods of isolated intersection signals is also increasing. Among them, fuzzy control is very popular in the field of traffic control [²] because it does not rely on the mathematical model of the controlled system. J. Guo proposed a particle swarm optimization to reduce vehicle delays based on Akcelik delay model [³]. Junjie Lu designed a two-step fuzzy controller for a isolated intersection system and optimized the controller parameters using a differential evolution algorithm. The results prove that the controller has achieved good control results [⁴]. M. J. Shirvani Shiri adopted a fuzzy control method to adjust the maximum green light time in response to real-time traffic conditions in an isolated intersection, proving the effectiveness and robustness of the proposed method [⁵-⁶]. D. Nagarajan proposed an improved interval neutron number scoring function using triangular interval type II fuzzy numbers and interval neutron number scores to control traffic flow by identifying intersections with more vehicles [⁷].

Based on the above discussion, this paper designs a type-two fuzzy controller. At the same time, the adaptive genetic algorithm was used to optimize the membership parameters
and fuzzy rule base parameters in the type-two fuzzy controller, so that it can adaptively adjust the parameters as the traffic volume changes.

2 Establishment of four phase isolated intersection model

In this paper, four phase isolated intersection is taken as the research object. The four signal phases are east-west straight phase, east-west left turn phase, north-south straight phase and north-south left turn phase. Most city intersections are equipped with vehicle flow detectors. Therefore, it is easy to obtain vehicle arrival information at every moment through technologies such as sensor detection and analysis and camera image processing. The queue length at the nth time point of a isolated intersection can be described as follows:

\[ L_G = \left( \frac{Q_G(n)}{p_G} - s \right) \times (l + H_d) - H_d \]  \hspace{1cm} (1)

\[ L_R^j = \left( \frac{Q_R^j(n)}{p_R^j} \right) \times (l + H_d) - H_d \]  \hspace{1cm} (2)

where, \( L_G \) is queue length of the current green light phase, \( L_R^j \) is queue length of red light phase. \( j \) is red light phase. \( Q_G(n) \) is current number of vehicles in green phase. \( Q_R^j(n) \) is the number of vehicles with red light phase. \( p_G \) is the current green phase lanes. \( p_R^j \) is the number of red light phase lanes. \( s \) is the saturated flow. \( l \) is the vehicle equivalent. \( H_d \) is the headway.

Vehicle delay is an important indicator for judging the effectiveness of the signal control system at intersections, and it is a standard for evaluating controllers. The relationship between queue length and vehicle delays is as follows:

\[ D_G = \sum_{k=1}^{n} z(Q_G(k) - skp_G) \]  \hspace{1cm} (3)

\[ D_R^j = \sum_{k=1}^{n} Q_R^j(k), \ j = 1,2,3 \]  \hspace{1cm} (4)

where, \( D_G \) is the vehicle delay with current green light phase. \( D_R^j \) is the vehicle delay with red light phase. When \( Q_G(k) - skp_G \geq 0 \), \( z=1 \); else \( z=0 \). Then the average vehicle delay \( d_i \) in period \( i \) are as follows:

\[ d_i = D_i / (q_i + s_i) \]  \hspace{1cm} (5)

where, \( q_i \) is the number of vehicles arriving in period \( i \). \( s_i \) is the number of vehicles stuck at a isolated intersection during the \( i \)-th cycle.

3 Design and optimization of controller based on type-two fuzzy

3.1 Design of Type-two Fuzzy Controller

In order to reduce the computational complexity of general type-two fuzzy systems in fuzzy reasoning and defuzzification, we use interval type-two fuzzy set expressions. Because the shape and control characteristics of the Gaussian membership function are relatively stable, it is more suitable to describe the magnitude of traffic at a isolated intersection. Therefore, we choose a type-two Gaussian membership function with uncertain deviation interval.
\[ \mu_A = \exp\left(-\frac{(x-m)^2}{2\sigma^2}\right), \sigma \in [\sigma_1, \sigma_2] \]  

(6)

where, \( m \) is the center of membership function. \( \sigma_1, \sigma_2 \) are the deviation of membership function. The input and output variables are divided into five levels of fuzzy division: "very short (VS)", "shorter (S)", "medium (M)", "longer (L)", and "very long (VL)". The design of the membership function is shown in Fig. 1.

![Schematic diagram of membership function.](image)

**Figure 1.** Schematic diagram of membership function.

Based on daily practical experience and past research, the initial fuzzy rule base is set as shown in Table 1.

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<tr>
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**Table 1.** Type-two fuzzy controller rule base.

### 3.2 Parameter optimization of adaptive genetic algorithm based on type II fuzzy controller

#### 3.2.1 Parameter optimization of membership function

The parameter optimization method of the adaptive genetic algorithm is used to adaptively adjust the crossover rate and mutation rate in the genetic algorithm to accelerate the convergence rate of the genetic algorithm and improve the adaptive performance of the parameter optimization method. According to the formula of the type-two Gaussian membership function of the uncertainty deviation interval, it is known that the parameter that needs to be optimized for each membership function is the center of the membership.
function and deviation of membership function. These parameters make up the individual \( E \).

\[
E_n = [m_n, \sigma_{1n}^2, \sigma_{2n}^2]
\]  

(7)

The total number of individuals in the population is set to \( N \). Each individual is randomly assigned within its own range to generate an initial population. Let \( K_m \) be the control parameter matrix for all individuals in the population.

\[
K_m = \begin{bmatrix}
E_1 \\
E_2 \\
\vdots \\
E_N
\end{bmatrix} = \begin{bmatrix}
m_1 & \sigma_{11}^2 & \sigma_{21}^2 \\
m_1 & \sigma_{12}^2 & \sigma_{22}^2 \\
\vdots & \vdots & \vdots \\
m_1 & \sigma_{1N}^2 & \sigma_{2N}^2
\end{bmatrix}
\]  

(8)

In order to obtain the optimal parameters, it is necessary to set the corresponding fitness function. For the isolated intersection signal control system, the average vehicle delay is an important indicator to measure the control system’s effect. Therefore, we use the evaluation index of vehicle delay as the fitness function of genetic algorithm

\[
F = \min\left[\frac{\sum_{i=1}^{M} d_i}{M}\right]
\]  

(9)

where, \( M \) is the number of cycles that have been run at the current moment.

3.2.2 Parameter optimization of type-two fuzzy rule base

In order to make the type-two fuzzy controller have better adaptive control effect and practicability, we need to optimize the rule base table of the type-two fuzzy controller as well. Then the optimization parameters are 25 rules in the rule table. The difference is that in order to facilitate the algorithmic calculation of the parameters in the rule base as individuals, the parameters in the rule base need to be digitally transformed.

\[
x_i = [0,5]y_i = \begin{cases} 
VS & x_i < 1 \\
S & 1 \leq x_i < 2 \\
M & 2 \leq x_i < 3 \\
L & 3 \leq x_i < 4 \\
VL & x_i \geq 4 
\end{cases}
\]  

(10)

The control parameter matrix of all individuals in the corresponding population is

\[
K_r = [E_1 E_2 \cdots E_N]^T = [x_1 x_2 \cdots x_N]^T
\]  

(11)

where, \( N = 25 \).

3 Simulation results

The simulation compares the average vehicle delay under three different control methods: timing control, type-one fuzzy controller and type-two fuzzy controller proposed in this paper. First, we explain the simulation process of a type-two fuzzy controller optimized for an intersection with traffic using an adaptive genetic algorithm. The flowchart is shown in Fig.2.
In order to show that the type-two fuzzy controller proposed is suitable for various traffic flow situations, we set two different vehicle arrival rates in the simulation experiment:

1. Arrival rate of straight vehicles is 600veh/s, arrival rate of turning vehicles is 300veh/s.
2. Arrival rate of straight vehicles is 800veh/s, arrival rate of turning vehicles is 300veh/s.

In the above simulation case, we have compared the timing control algorithm, the type-one fuzzy control algorithm, and the type-two fuzzy control algorithm proposed in this paper. The total simulation time is 1500s. Fig. 3 show the average vehicle delays for the two different vehicle arrival rates under these three different control methods.

![Figure 3. Average vehicle delay.](image)

Fig. 3 show the comparison of average vehicle delays at different vehicle arrival rates under three different control methods. We can see that among these three methods, vehicles with type-two fuzzy control have the smallest average delay and the slowest growth rate. And when the road is more congested, the control effect of the type-two fuzzy controller designed in this paper is better, which illustrates the superiority of the type-two fuzzy control system. Therefore, in the case of traffic congestion, the type-two fuzzy control method shows better control performance. The results show that it can more reasonably minimize the average vehicle delay and alleviate the long queue problem caused by the congestion.

### 4 Summary

This paper proposes an improved type-two fuzzy control scheme for four-phase isolated intersection signal control to reduce the average vehicle delay. An optimization algorithm for the membership function parameters and fuzzy rule base parameters based on adaptive genetic algorithm is proposed. The traditional timing control and a fuzzy control method
are compared through simulation. The control effect of the type-two fuzzy controller is more obvious which proves that the type-two fuzzy control method has better control performance.

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References


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