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Research on Traffic Congestion Resolution Mechanism based on Genetic Algorithm and Multi-Agent

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Abstract. In recent years, the number of motor vehicles in China has grown rapidly, and the contradiction between supply and demand of vehicles and roads has become more apparent. The problem of urban traffic congestion has become increasingly prominent, and the mechanism of congestion resolution has emerged. At present, there are still many shortcomings in China's traffic congestion control system. The phenomenon of urban road congestion is still widespread. The existing traffic control system cannot meet the complicated traffic network and cannot alleviate the deterioration of traffic conditions. This paper proposes a multi-agent traffic control system, which aims to control the green-signal and red-signal ratio of traffic flow at multiple adjacent intersections in the traffic network, thereby improving the driving ability of the traffic flow. This paper starts from the traffic control network and uses a single agent as the unit. Through multi-agent technology, the information between multiple agents at each intersection can be circulated, and each agent can quickly respond and automatically adapt to changes in traffic information. A genetic algorithm is used to establish a distributed urban traffic control system that can be continuously optimized. It is hoped that through the research in this paper, the problem of urban road traffic congestion deterioration can be effectively solved, thereby improving the vehicle traffic capacity and the efficiency of social activities.

Keywords: Traffic congestion; Multi-agent; Green-signal and red-signal ratio; Genetic algorithm.

1. Introduction

1.1 Research Background

While the social economy is developing rapidly, people's living conditions are constantly improving, and the value of time is getting higher and higher. Therefore, private cars have become the means of travel for many people; the development of transportation technology and transportation has become popular. At the same time, traffic congestion has appeared. The current traffic roads have not kept up with the growth of the number of cars, and traffic congestion has become increasingly serious. It has even become one of the major problems that restrict the development of cities in China and the world's major cities.

In recent years, urban road traffic congestion has gradually spread from large cities to small cities and even townships around. Although many cities have taken corresponding measures to build or expand urban roads, traffic congestion is still not well resolved. According to hina Statistical Yearbook, during the 20 years from 1995 to 2014, the number of Chinese private vehicles and passenger cars continued to grow, and the average growth rate exceeded 10% [1].

In recent years, China's car ownership and its year-on-year growth rate are shown in the table 1:

The growth trend of China's car ownership during the 10 years from 2007 to 2016 is shown in the figure 1:

Table 1. Car ownership

Years	Total number of civilian vehicles (10,000 units)	Year-on-year growth	Total private car ownership (10,000 units)	Year-on-year growth
2016	18574.54	14.06%	16330.22	15.83%
2015	16284.45	11.55%	14099.10	14.26%
2014	14598.11	15.22%	12339.36	17.50%
2013	12670.14	15.89%	10501.68	18.82%
2012	10933.09	16.85%	8838.60	20.63%
2011	9356.32	19.92%	7326.79	23.32%
2010	7801.83	24.22%	5938.71	29.81%
2009	6280.61	23.16%	4574.91	30.66%
2008	5099.61	17.01%	3501.39	21.74%
2007	4358.36	\	2876.22	\

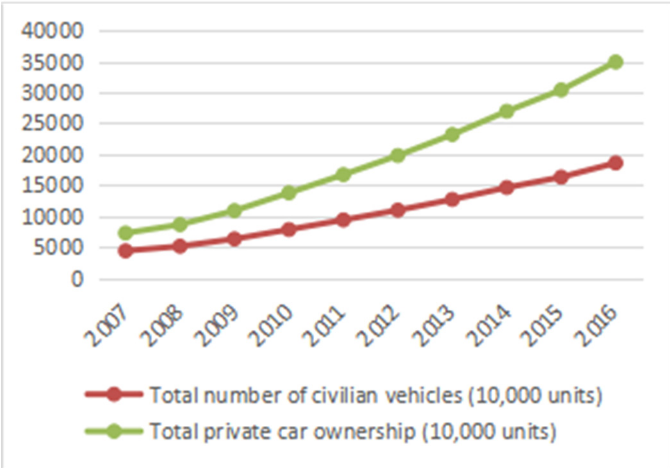

Fig 1. Car ownership growth

In 2014, China's car production and sales ranked first in the world, and is still developing [2]. It can be seen that the number of motor vehicles in cities is still growing, leading to the continuous deterioration of urban road traffic congestion, increasing the capital investment of cities, greatly reducing the efficiency of social activities and causing economic losses.

The basic methods for solving urban road congestion in China are:

(1) Establishing viaducts and widening roads. However, a city has limited space and huge construction costs, and it is impossible to expand the road without limit.

(2) Advocating the use of public transportation facilities such as public transportation and subway. However, due to the rapid expansion of the urban population, especially the peak of the “death subway”, the public transportation facilities cannot meet the travel needs of citizens.

(3) Offering products related to traffic jams in the market, such as navigation and high-tech maps. Although the software can be used to view the real-time traffic conditions of the road to avoid congested road sections, this method cannot really eliminate congestion, and can only transfer congestion from one place to another.

(4) Limiting the number of vehicles on the road, such as “odd-numbered cars and even-numbered cars on the road”, “permission to ride for four days and prohibition of riding for another four days”. This method can only reduce the probability of traffic congestion, and the total number of urban cars is increasing day by day. Moreover, many car owners have more than one private car, so it is difficult to reduce the traffic density by restricting the number of vehicles on the road; besides, it is hard to maintain the mitigation effect.

The congestion solution proposed above is a method for palliative treatment, which can only temporarily alleviate a small part of the congestion. Therefore, the research on traffic congestion resolution is especially critical for the development of a city.

1.2 Research Purposes and Significance

The phenomenon of urban road traffic jams is becoming more and more common, and effectively solving traffic congestion is an urgent problem for the current social development. The use of intelligent traffic control system is currently a more effective way to solve road traffic congestion. It is vital to improve the use efficiency of existing road facilities by controlling traffic signals, maximize the utility of existing facilities, achieve resource optimization, and reduce congestion.

1.3 Research Status at Home and Abroad

Although domestic scholars have started late in the study of urban road traffic congestion, focusing on the 21st century, they have certain achievements. In 2005, Yan Yulong et al. used saturation as an indicator to judge the status of intersections. Based on the experience of the green signal ratio optimization model, the experience of traffic police command intersections was used to give priority to the traffic flow sections with preferential traffic congestion. The road section has more green time to reach the goal of dissipating congestion at the intersection as soon as possible [3]. In 2014, Tan Fei proposed that an effective method to alleviate traffic congestion is the traffic intelligent control system such as SCOOT [4].

Foreign scholars' research on urban road traffic congestion is relatively earlier compared with domestic ones. Since the 1960s, many control methods and strategies have emerged. In 1964, Gazis first divided the intersection status into saturated and unsaturated states based on the remaining vehicles on the road after the end of the green light, and proposed a fixed signal timing strategy for rotating the release traffic at large green time in saturated state [5]. This is the first time in the world to propose the concept of traffic signal control. In 2001, Judd G. A proposed a green signal ratio optimization method considering the length of the imported lane with the capacity as the objective function, which can effectively reduce the congestion of the road network [6]. In 2010, Javier J et al. used genetic algorithm and cluster computing technology to optimize the signal. The results show that this method can effectively alleviate traffic congestion [7].

SCATS, SCOOT and other systems are the most widely used signal control systems in foreign countries, and these systems have achieved good results in practical applications.

Although the existing research has been widely used, in the complex urban road network, the number of vehicles is large, the number of traffic signals is huge, and the sudden situation is difficult to respond quickly, which greatly affects the optimization of urban traffic signals.

Aiming at the problems existent in the existing traffic network, this paper proposes a hierarchical genetic control algorithm based on multi-agent (Agent) technology. The genetic algorithm can make fast calculations and adaptive adjustments when the traffic volume changes, adjust the duration of the traffic lights, and improve the green signal ratio of the traffic flow, so as to improve the traffic capacity of vehicles at various intersections, thereby alleviating the problem of deterioration of traffic congestion.

2. Traffic Congestion Control Principle

2.1 Definition of Traffic Congestion

At present, there is no accurate and specific definition of traffic congestion in the world. The general definition is that traffic congestion is a phenomenon of vehicle queuing caused by the number of traffic on the road exceeding the capacity of the road network itself within a certain period of time [8].

2.2 Existing Traffic Control Systems and their Shortcomings

At present, the most widely used traffic congestion control systems in the world mainly include SCATS system and SCOOT system, but their control effects are limited and cannot be well adapted to the current urban road traffic congestion. The main reasons are as follows.

The SCATS system is a typical solution-selective timing control system [9], which prepares four green-signal and red-signal ratio schemes for each intersection for real-time selection. Therefore, SCATS have obvious limitations. When the road conditions change, the system chooses the green signal ratio that is compatible with the current situation. However, in the case of changing traffic conditions, the scheduled time is relatively short and the effect is not good, and traffic congestion can only be temporarily relieved. Therefore, SCATS's solution-selective system is a system with limited lag and limited capacity, and cannot quickly evacuate traffic congestion.

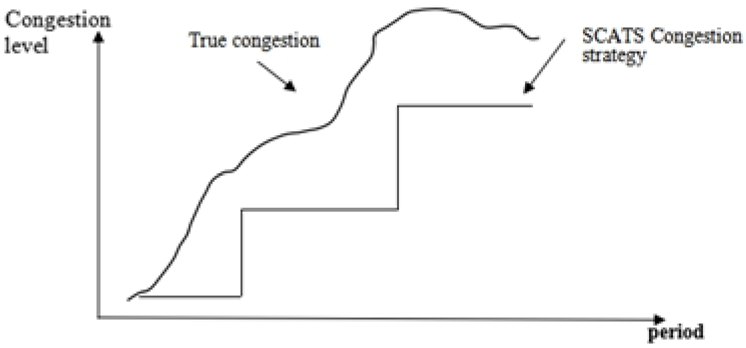

Fig 2. SCATS congestion strategy diagram

SCOOT is a scheme-based road network control system that optimizes the timing scheme of each intersection by collecting traffic demand at intersections, thereby minimizing vehicle parking times and vehicle delays at intersections. The small step size adjustment strategy adopted by SCOOT can be closer to the current road traffic conditions. However, its shortcoming is that when the traffic volume changes greatly, the system needs to change the control parameters on a large scale, but the strategy response speed of the small step is too slow to adapt to the current road congestion and evacuation situation. When the system reacts, Congestion may have been transferred to another place. Therefore, the system cannot meet the requirements of quickly evacuating congested traffic.

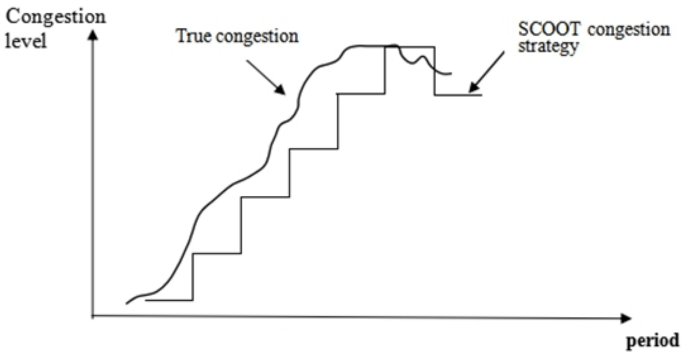

Fig 3. SCOOT congestion strategy diagram

2.3 New Features of New Congestion Evacuation Systems

In the current urban road traffic congestion, the road network of the traffic control system should have new features and consider the congestion control method from different angles. In view of the above statement, the following new features of the new traffic congestion evacuation system are proposed:

(1) Collecting data in time: To avoid delays in data and information, the system is required to collect traffic flow data of the current road in time;

(2) Quickly calculating the optimal solution: the system should be able to respond quickly according to the current traffic information, quickly calculate the optimal green light signal duration, and avoid the spread of congestion to other areas;

(3) Multiple intersection signals operate independently: the signal lights of each intersection can react separately to avoid the entire traffic network.

(4) Information sharing at all intersections: The traffic lights at intersections in urban road networks can exchange and share information together. Each intersection signal can cooperate with each other to obtain an optimal solution based on its own information and vehicle flow information of adjacent intersections.

Only the congestion evacuation system with the above characteristics can effectively control the current urban traffic congestion. This paper will study the urban traffic congestion resolution mechanism for the above points.

3. Multi-agent Technology

3.1 Multi-agent Technology Model

The main goal of the agent is to adaptively sense the changes in the environment and to optimize the operation of the environment. It uses sensors to sense the environment people provide to it, then computes the environment and then uses the actuator to perform the operation. The relationship between the agent and the environment is as follows:

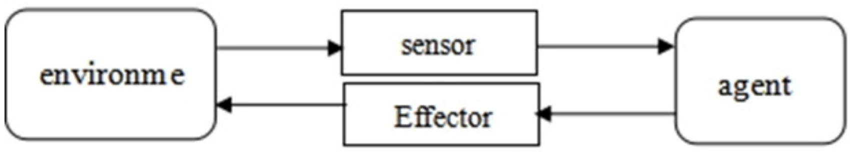

Fig 4. Relationship between agent and environment

According to the relationship between the above agents and the environment, the basic structure of multi-agent interaction is shown in Figure 5:

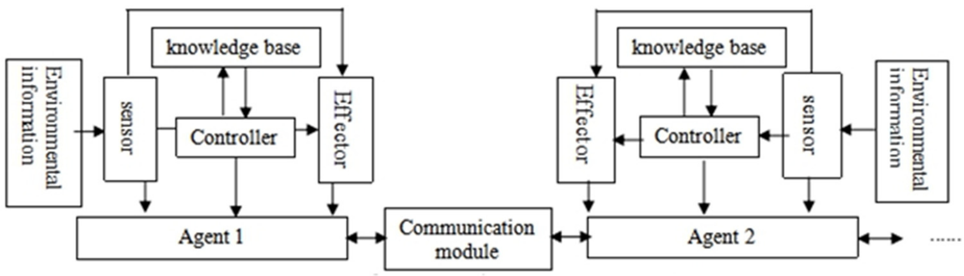

Fig 5. Basic structure of a multi-agent

Among them, the role of the sensor is to sense changes in the external environment; the controller is the control center and knowledge decision center of the system; the effector reacts to the external environment, affecting and changing it; the information and data of the knowledge base are derived from the pair of agents. External sensing; the role of the communication module is to assist the agent to exchange internal information.

The multi-agent is composed of a plurality of individual agents, which is a computing system with multiple agents that communicate and cooperate with each other in the environment.

4. Traffic Signal Control System based on Multi-Agent Technology

The ultimate goal of traffic congestion evacuation is to improve the traffic capacity of the vehicle. The time control of the green light duration is the key to the overall system control. When the traffic flow changes, the original green light duration of the system can no longer meet the current traffic flow. The traffic capacity of the vehicle is shown in the following equation [10]:

$$ci=si \cdot \lambda i \quad (1)$$

$$\lambda i=gi/tc \quad (2)$$

Where, ci is the traffic capacity of the vehicle (pcu/h); si is the saturated flow rate, ie the maximum traffic flow (pcu/h); λi is the green signal ratio; gi is the green light duration (s); tc is the signal period (s).

It can be seen that to improve the traffic capacity of the traffic flow, the key is to find the most suitable green light duration in real time; that is, to improve the green signal ratio of the traffic flow. Therefore, the following is aimed at urban road traffic flow, based on multi-intelligent technology and using a stratified genetic algorithm with rapid response and fast calculation, to optimize the traffic flow green signal ratio, thereby improving the traffic capacity of the vehicle.

The multi-agent-based traffic signal control system proposed in this paper can independently solve the adjustment strategy of the green signal ratio duration. The system adjusts the rate of increase of the green signal ratio by sensing the length of the traffic flow in the congested section. The longer the congestion, the greater the ratio of the green signal ratio. The adjustment plan is as follows:

Table 2. Green signal ratio adjustment plan

Fleet length ratio	Green signal ratio increase speed
10%	1%
20%	5%
50%	10%
70%	25%
80%	50%

Among them, the captain ratio refers to the percentage of the congestion of the two teams; the upward speed refers to the growth rate of the green signal ratio.

(1) When congestion begins, the green signal ratio starts to adjust upwards at 1% speed, increasing the waiting time of the green light signal;

(2) When the length of the fleet reaches 50% of the distance between the two intersections, it is regarded as moderate congestion, and the system automatically raises the green signal ratio by 10%;

(3) When the length of the fleet reaches 70%-80% of the distance between the two intersections, it is regarded as severe congestion, and the system automatically raises the green signal ratio by 25%-50%.

4.1 System Component

The system adopts a distributed control principle, without a central controller, and uses an independent autonomous method. The distributed control system consists of a total control center, a regional control center and a single intersection control center. In this system, the traffic data of the intersection control center is the key of the whole system. The adjacent intersections share information and cooperate with each other. Adjust the green signal ratio to achieve the time-optimized optimization scheme of the local adaptive traffic signal.

4.1.1 A Single Agent on the Road

It consists of traffic lights, sensors and cameras and is a core component of the system. The traffic condition at a single intersection is determined by the traffic flow conditions of the intersection itself and the traffic conditions of its adjacent intersections [11]. The single intersection agent shares and stores information with the adjacent intersection agent according to the traffic information transmitted from the camera and the vehicle detector, and then optimizes the signal timing scheme of the current intersection according to the traffic information transmitted from the adjacent intersection, and adopts hierarchical genetic inheritance. The algorithm quickly calculates the optimal green-signal and red-signal ratio of the current intersection and changes the duration of the traffic light.

4.1.2 Regional Agent

The centralized control center of all intersection agents in each section is the central layer of the control system and is responsible for the monitoring of the intersections in the area. Communication and cooperation with the adjacent areas are necessary to coordinate and control the timing scheme according to the traffic flow information shared by the regional road section agent.

4.1.3 Total Control Center Agent

The centralized control module of each regional control center agent is the highest level of the whole system, sharing vehicle flow information with the regional agent, real-time monitoring of the change of traffic flow in the regional road section; with the highest decision-making power, it is the management center of the entire control system and each detection center of the regional agent.

4.1.4 Coordination Mode

A single intersection agent uses a blackboard model for coordination [12]. The blackboard model has a blackboard for sharing information between adjacent agents. Each agent can share the real-time traffic information transmitted by the vehicle sensor on the blackboard. Based on this traffic information, a new timing scheme is developed until the latest optimal solution is calculated and presented to the traffic signal in an optimal green signal ratio. The internal mechanism is shown in Figure 6:

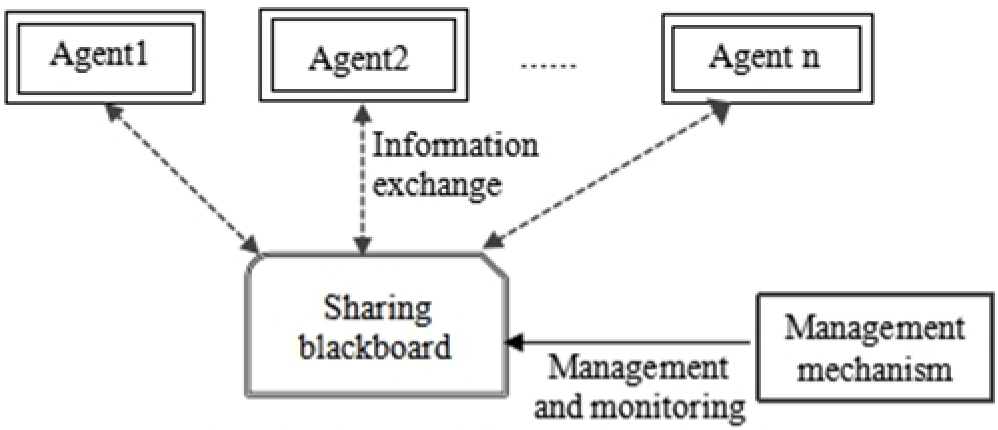

Fig 6. Green signal ratio adjustment scheme

4.1.5 System Structure

The key of the whole system control is the control scope of each agent. The system adopts an agent to control the signal of an intersection, and reduces the unnecessary sharing information between the agents. Each agent only needs to share information with the agents of the adjacent intersections and mutual Cooperation to ensure the overall optimization results of the system. The traffic signal control system based on multi-agent has the ability to sense the environmental change of the intersection and the ability to communicate with the adjacent intersection agent. The structure of the internal signal control system is shown in Figure 7.

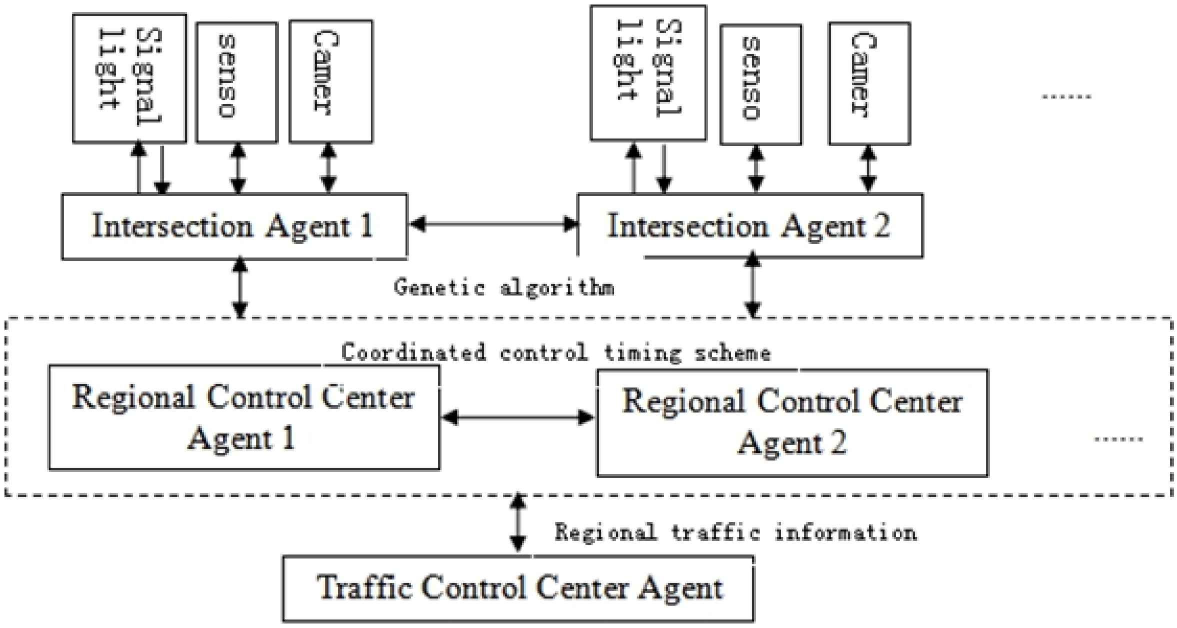

Fig 7. Multi-agent traffic light control structure

The system has the characteristics of high reliability, good timeliness, strong pertinence, high flexibility and strong adaptability. It can better adapt to various sudden changes in complex and huge traffic networks, and through hierarchical inheritance. The algorithm calculates the real-time optimal green-signal and red-signal ratio of the intersection more quickly.

5. Hierarchical Genetic Algorithm

5.1 Genetic Algorithm (GA)

5.1.1 Implementation Process

Genetic algorithm is a search algorithm that uses binary genetic coding. It can adaptively search and optimize the global problem. Its allele $A=\{0,1\}$, individual space $S=\{0,1\}$. Its genetic operation process is to cross and mutate all individuals in the whole, and its basic implementation process is as follows [13]:

(1) generating an initial population: Randomly select a moderate number of n individuals as the initial population $G(0)$, and setting an evolution algebra counter $t=0(t_{max}=T)$;

(2) Individual evaluation: Calculate and evaluate the fitness of all individuals in $G(t)$;

(3) Evolutionary population;

(3.1) selection (parent): based on the selection operator, select $a/2(a \geqq n)$ from $G(t)$ as the basis for population evolution;

(3.2) crossing: Using P_c as the crossover probability, some genes are extracted from the parent by $a/2$, so that the individuals in the population have gene exchange and generate a middle individual;

(3.3) variability: Artificially changing the genes of the intermediate individuals with P_m as the mutation probability, causing the individuals in the population to undergo artificial gene mutations to generate new a' candidate individuals;

(3.4) Selection (child): Based on the fitness of the individual population, n individuals are selected from the a' candidate individuals formed by the mutation to form a new generation of offspring population $G(t)'$.

(4) Termination test: If the final evolution criterion $t = T$ is satisfied, then the individual with the greatest fitness in the descendant population $G(t)'$ is the optimal solution of the problem, output the optimal solution, and terminate the calculation; $t' = t + 1$, repeat step (3).

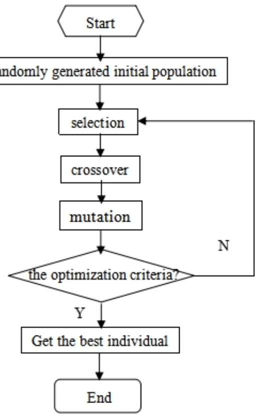

Fig 8. The Calculation Process

5.1.2 Inadequacies

But the genetic algorithm is not without its drawbacks. It still has the following shortcomings:

(1) The coding is not standardized, together with the uncertainty of the coding;

(2) The simplification of coding does not fully represent the constraints of the optimization problem, but instead increases the time of calculation;

(3) It is easy to prematurely converge;

(4) The solution of the genetic algorithm is uncertain.

5.2 Hierarchical Genetic Algorithm based on Multi-Agent

Because the genetic algorithm is random, it does not guarantee the optimality, but it can find a near optimal solution in a significantly smaller time [14]. Based on the genetic algorithm, this paper proposes a hierarchical genetic algorithm. The layered idea gradually gets the optimal solution closer to the problem. The genetic algorithm is used to layer the better green signal ratio solution generated by each intersection agent, and the process of re-crossing and re-mutation is performed in the selected better green signal solution set, and the optimal solution is calculated; hence the appropriate optimal solution.

5.3 The Process of Optimizing the Green Signal Ratio by using Hierarchical Genetic Algorithm

The genetic algorithm is run on the initial green signal ratio population in each intersection agent. When the algorithm runs to a certain number of algebras, the N green signal ratios obtained are recorded on the two-dimensional array $R[i，j]$, and in the array. The average fitness value of the N green signal ratio populations is recorded in $A[i]$.

Where $R[i，j](i = 1...N，j = 1...n)$ is the jth individual of the i-th green-signal and red-signal ratio population; $A[i](i = 1...N)$ is the fitness value of the green-signal and red-signal ratio population i.

(1) Selection: using genetic algorithm to calculate multiple green-signal and red-signal ratio of multiple intersection agents, and obtain the average fitness value array $A[i]$ of N green-signal and red-signal ratio, and then the green-sense ratio population in array A Then re-screening, the green $A[i]$ fitness ratio population with high fitness is preserved and enters a new round of crossover; the green signal ratio population with low average fitness value is eliminated.

(2) Crossover: randomly select two arrays of $R[i]$ and $R[j]$ as the parent A and B in the green signal ratio population, randomly cross the genes of the two parents to generate two new descendants A' , B' , equivalent to the exchange of n individuals in the A and B green signal ratio population.

(3) Variation: n new green signal ratios are randomly selected and cross-interleaved with n green signals randomly extracted from the array R[i，j] .In the regenerated new green signal ratio population, the respective operations are continued, and the loop operation is performed until the green signal ratio is satisfied, and the optimal green signal ratio is output.

The basic process of using genetic algorithm to optimize the green signal ratio is shown in Figure 9:

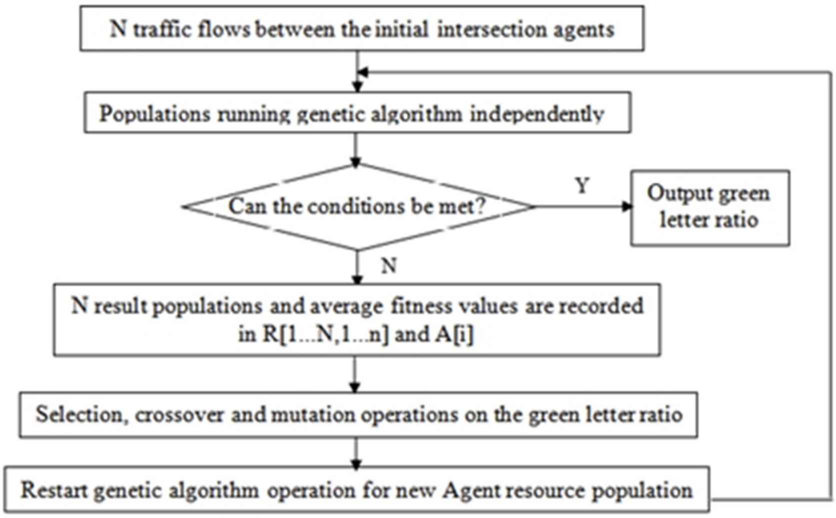

Fig 9. The process of optimizing the green letter ratio by hierarchical genetic algorithm

Each intersection agent responds to the change of the traffic flow sensed by its sensor, obtains N traffic flow information, independently runs the genetic algorithm, achieves N green signal ratios and performs global search in these green signal ratios. After some excellent green signal ratio is obtained, it is transferred to the search area of the key green signal ratio. After reaching a certain level, it is transferred to the new green signal ratio to narrow down the search range. Finally, the system adaptively crosses and mutates the green signal ratio in order to improve the defective green signal ratio, and further find the optimal green-signal and red-signal ratio under the circumstances of ensuring better green-signal and red-signal ratio, and output the green signal ratio control scheme until the best is achieved.

6. Conclusion

In the era of rapid development of urbanization, due to the characteristics of urban traffic network distribution, distributed intelligent traffic control systems are essential for urban road traffic congestion and evacuation. Based on multi-agent technology and based on the traffic signal control system of urban roads, this paper establishes the structure of traffic signal control system based on multi-agent technology. Based on the genetic algorithm, it introduces the idea of layering and proposes hierarchical inheritance. The algorithm greatly improves the defects of the operation lag of the previous traffic control system, and calculates the optimal green-signal and red-signal ratio that is adapted to the current traffic conditions faster and more accurately, thereby improving the traffic capacity of the traffic flow.

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