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Agent-Oriented Fuzzy Traffic Control Simulation

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ABSTRACT

Urban traffic situations are extremely complex and highly interactive. The multi-agent systems approach can provide a new desirable solution. Currently, a traffic simulator is needed to understand and explore the difficulties in an agent-oriented traffic control. This paper presents an agent-oriented fuzzy logic controller for multiple crossroads simulation. A fuzzy logic control simulation with variables of arrival, queue, and traffic volume could alleviate traffic congestion. We developed an agent-oriented simulator suitable for traffic junctions with $n \times n$ intersections in Visual C++. The proposed method adaptively controls the cycle of traffic signals even though the traffic volume varies. The effectiveness of this method was shown through simulation of multiple intersections.

1. Introduction

Nowadays road conditions have worsened due to traffic congestion caused by the continuous increase in the number of vehicles. Thus, it has become ever more important to manage traffic flow efficiently to optimize utilization of existing road capacities. High fuel costs and environmental concerns also provide important motives for minimizing traffic delays. The task of driving in traffic junction network is very complex and most of the traditional approaches cannot fully fix it. Automated traffic control technology has been widely applied to optimize traffic signal timing plans to facilitate vehicle movement.

Previous work has been done on the problem of controlling traffic junction. Prefixed controller, where every control parameter including phase sequence and cycle is fixed, determines the next phase by using TOD (Time of Day) plan. The most common traffic control system used in the U.S. is the Urban Traffic Control System (UTCS), developed by the Federal Highway Administration in the 1970s [1]. The UTCS generates timing schedules off-line on a central computer system based on average traffic conditions for a specific TOD. This method does not respond adequately to unpredictable changes in traffic demand.

With the development of cheap processors, several real time adaptive traffic control systems were developed in the early 80's to solve this problem. These systems can respond to varying traffic demands. An actuated controller that has no predetermined timing plan adjusts traffic lights by constant unit extension time according to the number of detected vehicles. When the distribution of traffic patterns is not static, this method lowers the efficiency of traffic lights that spend unnecessary green time. However, all of these methods do not cope with traffic junctions where the vehicles flow dynamically. Most urban areas nowadays experience severe traffic jams on street networks. As the traffic congestion spreads, there is a need to apply intelligent algorithms to diminish the waste of time, air pollution, and so on. Agent-oriented fuzzy traffic control allows inexact traffic data to be manipulated as a useful tool in designing traffic signal timing plans adaptively.

With the development of computation technologies, distributed artificial intelligence (DAI), so called multi-agent systems (MAS) approach and cooperative problem solving approaches may help to handle this problem. They offer certain advantages for problem solving: faster response, increased flexibility, robustness, resource sharing, and better adaptability [2]. Much of the strength comes through cooperation and communication. It relates to how the elements of a loosely coupled network can work together to fix the problems that are beyond their individual capacities. Each problem solving node in the network is capable of solving sophisticated problems and can work independently. However, the problems faced by nodes cannot be solved without cooperation.

This paper is organized into five sections. Section 2 introduces previous works. In section 3, the design and implementation of the proposed agent-oriented fuzzy traffic control simulator are described. Traffic simulation results are presented in section 4. Section 5 is conclusions.

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2. Previous researches

In this section, we describe agent-oriented traffic systems and fuzzy traffic control approaches because we have chosen fuzzy theory as a main control algorithm to adjust traffic signal plans.

2.1 Agent-Oriented Traffic Systems

The concept of agents is caused by outgrowth of the research during the past half-century on AI. The idea of a software entity that could perform tasks on behalf of a user as well established by the mid 1970's. This background brings in concepts of reasoning, knowledge representation, machine learning, and especially planning. The practical applications of agents have more pragmatic origins. Nowadays many problems are very complex, so multi-agent systems (MAS) which refers to all types of systems composed of multiple autonomous components are utilized to many application areas.

There are several works on the agent-oriented traffic control systems. As an earlier MAS applied to traffic problem, Lesser and Corkill presented distributed vehicle monitoring task [3]. In this system, a set of agents are distributed geographically, and each is capable of sensing some portion of an overall area to be monitored. As vehicles move through its sensed area, each agent detects characteristic sounds from those vehicles at discrete time intervals. From the analysis of the sounds, an agent develop interpretations of what vehicles might have created these sounds. This system shows the possibility of MAS.

Findler and Stapp proposed a distributed approach to optimized control of street traffic signals [4]. In this work, every intersection runs an identical expert system and communicates directly with the four adjacent intersections. The information transmitted can be raw data and processed information. The rule-base of the expert systems has a natural segmentation, corresponding to different prevailing traffic patterns and the respective control strategies. However, they categorized rules artificially and used them.

Li *et al.* developed a MAS model for three layered urban traffic control simulator [5]. The highest layer is the global urban traffic agent, executing the global planning. The middle layer is composed of some traffic flow control agents, executing group planning. The lowest layer has many individual traffic agents, executing individual planning. The most important individual traffic agents are vehicles, streets, junctions, and traffic lights. In this system, only the simulation for individual traffic agents was described.

2.2 Fuzzy Traffic Control

Several works have been done in the field of the adaptive traffic systems using fuzzy logic concepts since the late 1970's. Most of these works have focused on the control traffic lights at a road junction.

Pappis and Mamdani presented a fuzzy logic controller (FLC) for a traffic junction of two one-way road [6]. The FLC uses three linguistic input variables and one linguistic output. The fuzzy input variables are the passed time of the current interval, the number of vehicles crossing an intersection during the green phase, and the length of queuing from the red direction. The extension time calculated using 25 fuzzy rules is the output. This FLC was simulated at less critical intersections.

Gomide *et al.* proposed a FLC with adaptive strategies for fuzzy urban traffic systems [7]. The FLC adjusts the membership functions according to the traffic conditions to optimize the controller's performance. However, all membership functions are adapted concurrently. So, the relation from one membership function to the others remains the same.

Jamshidi *et al.* developed a simulator for fuzzy control of traffic systems [8]. This FLC decides whether to change the state of the light or remain in the same state. Simulations are not confined to one-way road systems, but the signal program is restricted to two fixed directions of traffic. The controller is unable to respond to main traffic flows that change and turn.

Ho provided a fuzzy traffic controller (FTC) at an intersection with time-varying flow rates [9]. He found that a simple FLC with one fixed fuzzy rule-set was inadequate to minimize delays when traffic flow rate was changing. So, the FTC with fuzzy rule-sets adapted to changing traffic conditions was presented. However, this FTC used 9 fuzzy rule-sets according to arrival flow rates and queue flow rates. Owing to only many traffic control rules, it was possible to show good performance in traffic simulations.

Prior research has been done on the coordination of traffic signals. Chiu and Chand proposed the distributed approach to traffic signal control, where the signal timing plans at each intersection are adjusted using only local traffic conditions and coordinated only with adjacent intersections [10]. Recently Lee and Lee-Kwang have developed distributed and cooperative fuzzy controllers for traffic intersections group [11]. Their system changes both phase sequences and phase lengths of traffic signals adaptively to traffic conditions.

3. Proposed Agent-Oriented Fuzzy Traffic Control Simulator

This section explains the design and implementation of an agent-oriented fuzzy traffic control simulator.

3.1 Design of Agent-Oriented Fuzzy Traffic Simulator

Fuzzy traffic control simulator was developed by agent-oriented paradigm. We implemented the simulator suitable for traffic junction networks in Visual C++ to analyze traffic conditions and to calculate the optimized traffic signals [12].

Agent-oriented programming allows the simulation to be built in a modular fashion making it easily expandable and maintainable. As an example of agent-oriented programming by using MFC, if you make a new control algorithm and put it into the crossroad the algorithm works well.

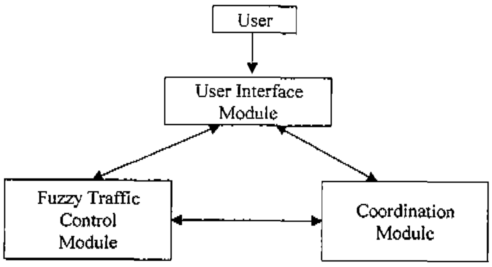

Fig. 1. Architectural view of proposed agent-oriented traffic simulation system

We designed an agent-oriented fuzzy traffic control system in the form of Fig. 1. As you can see in Fig. 1, there are three important modules including user interface (UI), fuzzy traffic control (FTC), and coordination module. The user interface module presents user with a graphical display representing the simulated traffic control environment. The fuzzy traffic control module adaptively controls the cycle of traffic signals regardless of traffic volume sets. The coordination module cooperates and coordinates traffic signals between neighboring intersections.

There are Car, Lane, Detector, Signal, and Crossroad agents in FTC module of Fig. 1. Fig. 2 shows the overall architecture of each single intersection which is a member consisting of target 4×4 crossroads.

We explain crossroad signal control process involved in individual agents. The information of cars detected between front and rear detector on each lane is used as an input parameter for signal control algorithm module in Crossroad agent. Detector agent takes responsibility of perceiving cars. Signal control algorithm module of Crossroad agent uses predefined signal control algorithm with detected information of cars to calculate the extension time of current controller. The extension

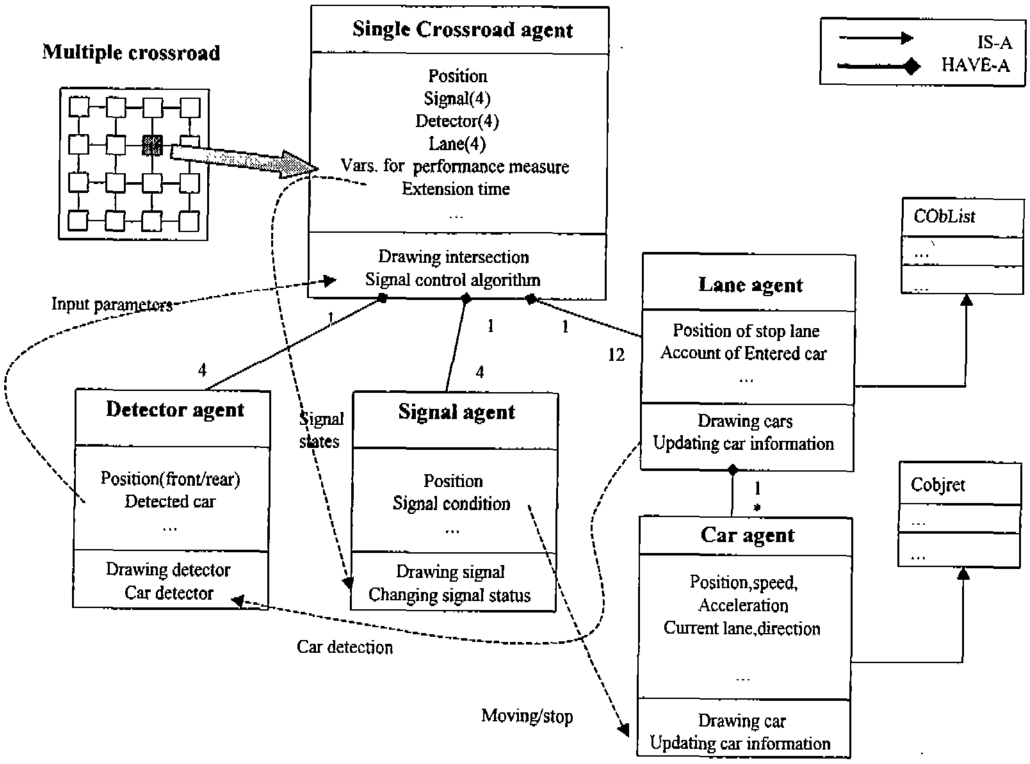

Fig. 2. The overall architecture of each single intersection consisting of 4×4 crossroads

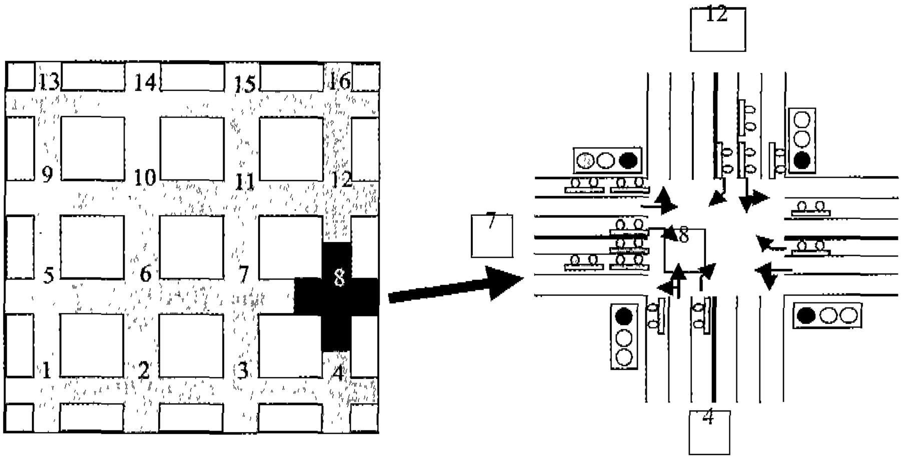

Fig. 3. Road condition of multiple crossroads used in the simulation

time adapts the signal state of Signal agent. All kind of controls happen in Crossroad agent. We can add several control algorithms to Crossroad agent easily by changing only signal control algorithm module of this agent.

3.2 Implementation of Agent-Oriented Fuzzy Traffic Simulator

We developed an agent-oriented simulator for benchmarking performance test of traffic signal control algorithms in 4×4 crossroads similar to real traffic networks. For an easy and practical simulation, the following traffic junction is assumed in this paper. First, there are three lanes for each direction. Second, the center lane is used for only through movements, the right lane for through movements and permissible turn right movements, and the left lane for only turn left movements. Third, the traffic densities are taken from two detectors on the road. The front detector is placed at the intersection and the rear detector 150 meters before the light. Length of each vehicle is 5 meters and distance between neighboring intersections is 400 meters. Fig. 3 shows road condition of multiple crossroads used in the simulation.

The vehicles were generated with Poisson distribution by using random function generator and have 16.67 (meter/sec) value as their initial velocity [13]. In the simulation, we use 4 phase cycles North-South (N-S) through movements, East-West (E-W) turn left movements, E-W through movements, and N-S turn left movements. Allocated time is 20 seconds for N-S through movements, 6 seconds for E-W turn left movements, 20 seconds for E-W through movements, and 6 seconds for N-S turn left movements. In also, two seconds are used for an amber signal.

3.3 FLC Suitable for Various Traffic Volumes

Conventional FTCs usually adjust the extension time of the green phase with the fuzzy input variables of arrival and queue. These fuzzy schemes usually utilize arrival and queue values while the controllers are in operation. Thus, these methods are inadequate for an intersection which traffic volume varies. Some traffic elements can be taken into consideration using the fuzzy control rules to diminish congestion.

For a FLC to be practical, it is designed to diminish the traffic congestion of intersections with variable traffic volumes. Thus, in this paper, we present a FLC using different control rules and different maximum extension time according to traffic volume and consequently vehicles can flow smoothly at an intersection [14]. The block diagram of our FLC is shown in Fig. 4.

The fuzzy input and output variables should be a reflection of traffic congestion. In this paper, volume as well as arrival and queue frequently used in the conventional FLCs are used as a new input variable of FLC. The FLC outputs the extension time of the current green phase, which can be extended until a maximum previously defined value is reached. Membership functions of each fuzzy input/output variable are in Fig. 5.

The control rules of the proposed FLC are divided

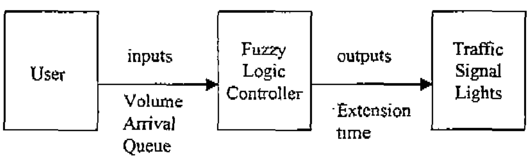

Fig. 4. The block diagram of our FLC

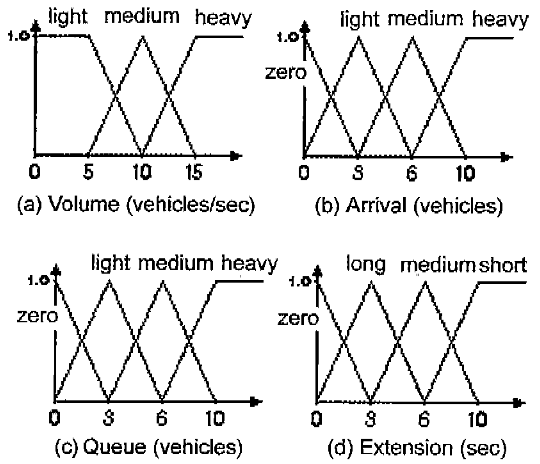

Fig. 5. The membership functions of fuzzy input/output variables

Step1	Inputs Volume, Arrival and Queue.
Step2	Computes the membership grade of Volume variable.
Step3	Chooses the group with the maximum grade value and uses its control rules.
Step4	Computes the membership grades of Arrival and Queue variables.
Step5	Determines the extension time by using fuzzy control rules and the membership value of Arrival and Queue variables.

Fig. 6. The algorithm to determine the extension time of green phase

into 3 groups of light, medium, and heavy according to Volume [14]. Each group has different control rules. There are 5 rules for light group, 9 for medium group, and 7 for heavy group. The number of total control rules is 21. The algorithm to determine the extension time of green phase is shown in Fig. 6.

4. Traffic Simulation

In this paper, we compared the proposed FLC with prefixed controller and Gomide's FLC in terms of delay and cost function. Delay is a good performance measure to evaluate traffic controller [13]. The average delay (d_m), which is defined in Equation (1), is the ratio of the number of detected vehicles to the total delays during the whole green and red periods [6].

$$d_m = \frac{D_R + D_G}{\sum_{n=1}^{R+G} q_n} \qquad (1)$$

where D_R and D_G are the delays during R and G, i.e., the red and green signal periods, respectively. The symbol q_n is the number of counted vehicles during R and G.

We utilized cost function designed by Jamshidi [8] as another measure. Cost function, which is defined in Equation (2), considers all vehicles entered and exited junctions, and moving and stopped time of vehicles. So, our goal is to reduce average delay and cost function value if possible.

$$\text{cost function} = 100 \times \frac{time_{wait}/time_{drive}}{cars_{exit}/cars_{enter}} \qquad (2)$$

where $cars_{enter}$ and $cars_{exit}$ are the number of vehicles entering and exiting the traffic network, respectively. The $time_{drive}$ and $time_{wait}$ are the average drive time and waiting time, respectively.

In the simulations, N-S direction was considered as an arterial road and E-W being the direction for a side road respectively. Table 1 shows four combinations of traffic volumes used in the simulation. The values in the table indicate the flow rates for each direction. In this simulation, 10% and 20% of vehicles were generated for turn left and turn right movements, respectively. That means only 70% of vehicles are generated for through movements and applied to FLC. Simulations for four traffic volume sets in Table 1 were conducted on 4×4 traffic intersections for 30 minutes, respectively.

Table 1. Sets of traffic volumes used in the simulation

Case \ Direction	North	South	East	West
Case 1	5	5	5	5
Case 2	10	10	5	5
Case 3	15	15	5	5
Case 4	15	15	10	10

Table 2. Simulation results of prefixed controller and the proposed FLC

(a) average delay			
Delay(sec)	Prefixed	Proposed	Improvement(%)
Case 1	21.0	11.2	46.7
Case 2	21.7	11.6	46.5
Case 3	21.6	10.0	53.7
Case 4	21.7	10.0	53.9

(b) average cost function			
Cost function	Prefixed	Proposed	Improvement(%)
Case 1	82.6	68.7	16.8
Case 2	90.9	78.5	13.6
Case 3	95.6	67.7	29.2
Case 4	87.4	66.1	24.2

Table 3. Simulation results of Gomide's and the proposed FLC

(a) average delay			
Delay(sec)	Gomide	Proposed	Improvement(%)
Case 1	11.9	11.9	0
Case 2	11.9	10.3	13.4
Case 3	11.9	9.6	19.3
Case 4	12.0	9.9	17.5

(b) average cost function			
Cost function	Gomide	Proposed	Improvement(%)
Case 1	73.2	72.7	0.7
Case 2	82.7	70.9	14.3
Case 3	85.6	69.1	19.3
Case 4	79.9	67.5	15.5

Table 2 shows the simulation results of prefixed controller and the proposed FLC in terms of average delay and average cost function. Compared to prefixed controller, the proposed FLC yields an improvement of 50.2% and 21% on the average delay and the average cost function, respectively. In the case of heavy traffic for both vehicle directions, the proposed FLC shows much better performance.

Table 3 gives the simulation results of Gomide's and the proposed FLC in terms of average delay and average cost function. Compared to Gomide's FLC, the proposed FLC yields an improvement of 12.6% and 12.5% on the average delay and the average cost function, respectively. Especially Table 3 indicates that the proposed FLC shows much better performance when traffic volumes of both vehicle directions are heavy.

From Table 2 and 3, we observed that the proposed FLC reduces delay time of vehicles and cost function values by introducing traffic volume parameter into fuzzy input variables. Thus, the proposed FLC is useful for applying multiple crossroads having complex road structure like real traffic conditions.

5. Conclusions and Future Work

A new agent-oriented FLC has been proposed. Conventional fuzzy controllers are designed to improve performance of controllers in the case of uneven traffic flows. We introduced the traffic volume parameter into the conventional fuzzy controller to improve the performance of FTC suitable for urban crossroads with time-varying flow rates.

In this paper, we implemented an agent-oriented multiple crossroad simulator with $n \times n$ intersections to evaluate the performance of the traffic signal control algorithms. We utilized agent-oriented paradigm to extend or maintain developed system easily. Since our real traffic situation is suitable to design agents on urban road networks, we chose agent-oriented scheme to develop traffic simulator. The developed simulator can be tested specific traffic situations by changing input parameters like traffic volume sets. The proposed FLC has been applied to crossroads with various traffic flow rates. The simulation results indicate that the proposed FLC yields lower average delay and lower average cost than conventional controllers. This verifies that the proposed method fits the real needs at traffic junctions.

Further research is needed to develop more coordinated approach to solve cooperation and negotiation between neighboring traffic junctions. Also, protecting spillback phenomenon of multiple crossroads, we have to consider car size such as small automobile and large car, i.e., bus or trailer. In this paper, we have simulated on the crossroads, but real road has several traffic conditions including crossroads, 3-branch street, 5-branch street, and so on. So the experiments are needed for various practical traffic conditions.

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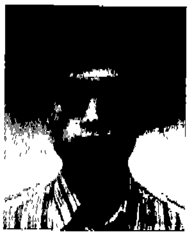

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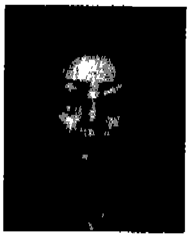

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