Design of On-line Simulation System for Signal Control of Urban Intersections Based on Visual Sensing Technology

Juanjuan Wang *, Yanan Wang, Hongfang Zhou
Xi’an Traffic Engineering Institute, Xi’an, 710300, China

*Corresponding author e-mail: wangjuanjuan@xjgy.edu.cn

Abstract. Intersection area is the area with the most serious conflicts and accidents in the whole urban traffic system. Therefore, it is of great significance to combine modern computer technology, sensing technology and communication technology to intelligently control intersections, improve the efficiency of traffic signal control and reduce the delay time in conflict areas. Starting with video detection and using deep learning in the detection module, a video detection mechanism based on restricted Boltzmann machine network is proposed. Based on C# programming language, the intersection traffic signal simulation module is designed through COM interface provided by traffic simulation software VISSIM, which realizes road network import, parameter setting, signal timing change, simulation operation and simulation result output. Numerical experiments show that fuzzy control method with self-correcting factor is superior to timing control method and classical fuzzy control method in average delay time of vehicles.

Keywords: Visual sensing technology; Urban intersections; Signal control; simulation system.

1. Introduction
With the worsening of traffic safety and environmental pollution, it is difficult to solve the increasingly serious traffic problems by relying on traditional traffic management methods. The emergence of intelligent transportation system provides us with new ideas and methods. As the core and development direction of intelligent transportation, intelligent network connection is the key to solve urban traffic congestion and improve vehicle traffic efficiency. Therefore, under the existing road conditions, how to improve the traffic control ability and management level, rationally use the existing road resources and give full play to their capabilities has become an important issue in traffic control [1]. At present, traffic control is developing in the direction of intelligence. Intelligent transportation system is a new technology that uses high-tech means to solve today's transportation problems and is the application of artificial intelligence technology in transportation systems.

75% of people's understanding of information comes from vision, and images and pictures can record the basic information needed more completely and clearly. Combined with the current off-site law enforcement system, based on the concept of deep system development and application, video technology is used to monitor all aspects of traffic [2]. Compared with the traditional detector, the vehicle detector and video image processing based on vision technology have the advantages of fast
speed, comprehensive information detection, convenient installation and maintenance, low cost, wide
detection range and more traffic parameters detection [3-4]. With the development of computer and
image processing technology, vision sensing technology has become an alternative vehicle detection
method, especially the use of machine vision detector, which may replace the traditional detector and
become an important detection method and component of modern intelligent traffic detection system
according to the development trend in the future.

Considering the role of traditional signal control in future traffic control and the special position of
simulation in traffic control, this paper preliminarily completes the design of the core layer of the system
based on visual sensing technology and adopts object-oriented Java language to preliminarily realize the
control system simulation software.

2. Visual sensing technology and image processing technology
Visual sensing can be far away from the detection target and collect a large amount of information. It
not only improves people's working environment and improves production efficiency, but also can be
used for lunar surface exploration, deep-sea unmanned exploration, satellite monitoring and so on. The
vision sensor converts optical signals into electrical signals, that is, the light intensity information
incident on the photosensitive elements of the sensor is converted into electrical signals which are
serially output according to time sequence, and then the images are acquired, stored, transmitted,
processed and reproduced through amplification and analog-to-digital conversion, and the acquired
images are stored in the computer memory in the form of gray matrix [5-6]. Fig. 1 is a typical vision
sensing system.

![Typical vision sensing system](image)

Figure 1. Typical vision sensing system

Image processing technology is a technology that analyzes, processes and processes images to meet
visual, psychological and other requirements. Since most images are stored in digital form, image
processing refers to digital image processing. When the visual sensor captures the original digital image,
it is often affected by various conditions and random factors. Therefore, it needs to be preprocessed by
image transformation, enhancement or restoration, in order to filter noise, correct gray scale and
distortion [7]. The preprocessed digital image can satisfy some applications, but for some demanding
applications, further image transformation, image segmentation, edge detection and morphological
processing are needed.

3. Simulation software design

3.1. Overall system structure
Based on the research of urban signalized intersections, this system comprehensively considers traffic
information collection and optimization of signal control, and designs an online simulation system
structure combining software and hardware, which is used to evaluate and analyze urban traffic signal
control schemes, and to debug and simulate them online. The system structure is shown in Figure 2, which can be divided into three parts according to functions: microscopic traffic simulation platform, traffic information collection part and traffic signal controller part.

Figure 2. On-line simulation system structure of signal control

The front end of the system is the traffic information collection part, which collects relevant traffic data information by setting detectors at intersections, such as vehicle queue length, traffic flow speed, crossing time, etc., and these information will be sent to the detector data control center through wireless communication; The microscopic traffic simulation platform is connected with the data control center through VISSIM_COM data interface, and completes the function of calling and collecting traffic information in real time.

3.2. Video detection mechanism based on restricted Boltzmann machine network

Intersection is a "big data" environment in which people, vehicles and roads are mixed. It needs a computer to simulate the human brain to recognize and distinguish things, so as to extract the required goals and parameters. Neural network is a machine learning model for information processing. For the case of a large number of research samples, simple neural networks can no longer meet the actual needs, so complex network models, such as deep learning models, are needed.

Deep learning based on restricted Boltzmann machine is adopted. In dealing with the front and rear occlusion of vehicles, the information of one to three local vehicles is taken as training samples to directly train the distribution of vehicles in an area (the maximum number of vehicles is because the algorithm is difficult to converge in the case of more people). The detection effect of this method is not as good as the recognition of a single vehicle when there are fewer vehicles, but when there are more vehicles, it will obviously inhibit the troubles caused by occlusion.

Restricted Boltzmann machine is a stochastic neural network defined by energy function and symmetrical in structure. Compared with Boltzmann machine, it has the disadvantages of long learning time and high complexity. Restricted Boltzmann machine has strong learning ability, can learn the complex information of original data, and meets the requirements of response speed in this paper [8].

Restricted Boltzmann Machine (RBM) is a network structure of abstracting image features, which can be used to reduce dimensions (fewer hidden layers), learn features (output of hidden layers is features), and deep network (stack of RBM). It consists of a hidden layer and a visible layer. The visible layer and the hidden layer have only two states: 0 and 1, and the state value can be calculated by probability statistics. (Assume that there are $m$ nodes in the hidden layer and $n$ nodes in the visible layer). Select the positive samples depending on the scene, which are not detected by the current detector, and the samples judged as positive samples by the comprehensive judgment analyzer are added to the current model, and the local weights are updated at the fully connected neuron layer.
Through these two cases, we can establish the energy formula of the network according to the basic formula of Markov probability undirected graph [9]:

\[
E(v, h|\theta) = -\sum_{i=1}^{n} a_i v_i - \sum_{j=1}^{m} b_j h_j - \sum_{i=1}^{n} \sum_{j=1}^{m} v_i W_{ij} h_j
\]

(1)

\[
P(v, h|\theta) = \frac{e^{-E(v, h|\theta)}}{z(\theta)}
\]

(2)

\[
z(\theta) = \sum_{v, h} e^{-E(v, h|\theta)}
\]

(3)

In which \(i\) is the visible node, \(j\) is the hidden layer node, and \(W_{ij}\) is the connection weight between the visible point \(i\) and the hidden point \(j\).

When the state of the visible layer is known, since each connection relationship is independent, the maximum probability of \(j\) hidden layer nodes can be obtained:

\[
P(h_j = 1|v, \theta) = \sigma \left( b_j + \sum_i v_i W_{ij} \right)
\]

(4)

\[
\sigma(x) = \frac{1}{1 + \exp(-x)}
\]

When the state of the hidden layer is known, since each connection relationship is independent, the probability of \(i\) visible nodes can be obtained at most:

\[
P(v_i = 1|h, \theta) = \sigma \left( a_i + \sum_j W_{ij} h_j \right)
\]

(5)

3.3. Main process of software design

The main flow of simulation software is realized in the thread class in view layer, that is, Run Paint class:

(1) Before starting

Before starting the simulation clock, initialize the simulation environment, which is mainly the road network object and the intersection traffic light signal control related objects. Includes initializing static parameters stored in the data layer, such as accessibility matrix of road network, physical location of road sections in road network, etc., and creating simulation environment objects.

(2) Starting up

When the simulation clock starts, the workflow of each simulation step program needs to be done:

1) Run the vehicle generation module to calculate whether there are vehicles entering the simulation area and the number of vehicles entering this cycle, and set relevant parameters for vehicles entering the road network: vehicle speed, starting lane, entrance node and destination exit point, etc.;

2) Scanning all vehicle objects in the simulation container in sequence until the end; In the scanning process, each vehicle object is introduced into the vehicle behavior decision object Run Agent in turn. This class and Run Base Agent object together determine the running speed and related vehicle running status signs for the vehicle in this cycle, and store the corresponding vehicle parameters into the vehicle object.

3) Scanning all vehicle objects in the simulation container in sequence until the end; According to the speed parameters and the corresponding status marks stored in the vehicle object, the final position of the vehicle in this cycle is determined, and the current position parameters in the vehicle object are updated. At the same time, store the basic parameters of decision-making for the next simulation cycle in the duplicate vehicle objects of current speed, position and running state.
4) Invoke the repaint() method of the Map Paint class object of the drawing panel to display the positions of all vehicles on the interface.
5) Thread hangs for 1 second;
3) End of simulation
   Exit the simulation thread when the simulation step is over or an end event is encountered; or when a pause event is encountered, the simulation clock is paused.

3.4. Signal control module
In the signal control module, four phases are set for users to use. Users only need to input the yellow light duration of the four phases and the green light duration of the first three phases, and click the scheme input button to get the green light duration of the fourth phase, the red light end time and the green light end time of the four phases. If the input yellow light duration is greater than 5, an information box will pop up, prompting the user that the input yellow light duration should not be greater than 5 and re-input; Because the green time of the left-turn phase should not be less than 7, if the green time of the fourth phase is less than 7, an information box will pop up to remind the user which phase the green time input is too long and locate in which text box; If the scheme input is correct, you can click the preview phase diagram button to visually see the duration of red light, yellow light and green light in each phase. At this time, the text of the preview phase diagram button also changes to close the phase diagram. Click again to close the phase diagram.

4. Experiment and interface design of online simulation system

4.1. Standard flow of traffic simulation engineering
Road traffic simulation mainly relies on computer as the main tool to reproduce the real traffic flow situation in time and space, which can better simulate and analyze the dynamic real-time effect of traffic organization scheme. Therefore, traffic simulation can provide a scientific tool and method for traffic organization and coordination, make the analysis of traffic problems more intuitive and reliable, and provide decision-making basis for traffic organization management and control [10].

The standardization process of traffic simulation engineering is shown in Figure 3.

![Figure 3. Traffic simulation engineering standardization flow chart](image)

First of all, it is necessary to analyze the simulation requirements and clarify the objectives and contents of the simulation experiment. Then, the intersection is selected to design the simulation project, and the traffic status is analyzed and investigated; Finally, according to the system design requirements, the data communication process between the simulation environment and the external signal control part is established, and the joint debugging process between the external signal control and the internal software simulation is established on the basis of software simulation, which has achieved the purpose of establishing the simulation experiment project.
4.2. Ways to set important traffic parameters
Traffic control system researchers, after studying the existing traffic parameters, get a certain control strategy, and then apply the control strategy to the simulation system. How to add the new control strategy into the simulation system is another problem that the simulation system needs to solve. There are two main types of control parameters:

(1) Traffic rule setting
The realization of traffic rules will be realized in data layer, model layer and control layer. The data layer stores the data expression of traffic rules; Model layer is the logical realization of traffic rules. In the control layer, the vehicle selects the traffic rules that need to be observed according to the running conditions, and calls the corresponding traffic rule model base.

(2) Traffic signal control settings
Then the scheme directly modifies the traffic light control scheme of the corresponding intersection in the data layer, that is, the traffic light time can be divided into phases.

4.3. Generation of fuzzy control response table
The core of fuzzy control system is fuzzy controller, and the performance of fuzzy controller has great influence on the system performance. The performance of fuzzy controller depends on the determination of control rules, which can also be considered to depend on fuzzy control look up table. In fact, the functions of quantization factors can be considered as weighting the input of the controller, and directly affect the performance of the system. Therefore, we choose the correction factor to adjust the rules. The fuzzy controller with correction factor can be expressed by analytical expression:

\[
\Delta T' = \text{round}(Q' \cdot (1 - \alpha)Q'_{\text{next}})
\]  

(6)

Here, \( Q' \) and \( Q'_{\text{next}} \) are used to represent the input quantization level, \( \Delta T' \) is used to represent the output quantization level, \( \text{round}() \) is rounded, \( \alpha \) is the weighting coefficient of the input quantization level, which is a real number between 0 and 0. By adjusting its value, the purpose of flexible control is achieved. In order to simplify the optimization process as much as possible and absorb the advantages of multiple correction factors, a fuzzy controller with self-correction factors in the whole universe can be expressed by formula (7):

\[
\begin{align*}
\Delta T' &= \text{round}(Q' \cdot (1 - \alpha))Q'_{\text{next}} \\
\alpha &= \frac{1}{N}(\alpha_s - \alpha_0)Q' + \alpha_0
\end{align*}
\]  

(7)

In the formula, \( 0 \leq \alpha \leq \alpha_s \leq 1, \alpha \in [\alpha_0, \alpha_s] \). \( \alpha \) is the correction factor, which changes between \( \alpha_0 \) and \( \alpha_s \) with the change of the absolute value of the quantization level. When \( Q' \) increases, \( \alpha \) also increases online, and \( \alpha \) has \( N \) values, which fully reflects the different requirements of the system for \( \alpha \) in different states. This process of automatically adjusting rules is more in line with people's thinking characteristics in control, and the algorithm is simple and practical, which is very easy to be realized by computer or microcomputer.

According to the membership functions of input and output variables and fuzzy control rules, the fuzzy relation matrix \( R \) can be calculated off-line. \( R \) is huge, which is not conducive to storage and online operation. Generally, the fuzzy control response table should be further worked out. In the actual control process, the fuzzy control look up table can be directly queried according to the input variable value after fuzzy quantization to obtain the output value \( \Delta t \) of the controller.

It is assumed that the arrival of vehicles in the intersection detection area is random, the saturated flow of each phase is 0.8 vehicles/s, and the traffic leaves the motorcade at a rate of 1 vehicle/s. Using the simulation system designed in this paper, the simulation program of fuzzy control with self-correction factor at different arrival rates of single intersection is written, and the setting parameter is \( k_q = 2.5, k_{q\text{next}} = 2.5, k_M = 2 \). Each simulation is 10 cycles, and the average delay time of vehicles is
calculated by the same method, and the effects of the three methods under different traffic conditions are compared. The simulation results are shown in Figure 4.

Figure 4. Comparison of simulation results

The simulation results show that the green light time is not fixed by using fuzzy controller, and the fuzzy rules are further dynamically adjusted to better adapt to the changing traffic flow, which can reduce the average delay of vehicles. Therefore, it is a feasible method to adjust the fuzzy rules of fuzzy controller by using self-correction factor.

5. Conclusion
With the development of social economy, people put forward higher requirements for travel. Intelligent and efficient urban road traffic signal control system is an important guarantee for the safe and orderly operation of urban road traffic. A video detection mechanism based on restricted Boltzmann machine network strategy is proposed to solve the problem of target vehicles and parameter extraction in complex scenes of actual roads, and effectively solve the occlusion problem when there are many vehicles. The system function is designed for the whole simulation system, and the functional areas of each component are divided. Finally, the scheme adopts the combination of geomagnetism and video detector to collect traffic information, selects VISSIM as the microscopic traffic simulation platform, and selects the centralized coordination control machine with mature technology in the market as the logic control unit of signal lamp, and completes the design of the whole signal control online simulation system.

References
[1] Fang Liqin, Duan Manzhen, Jake, et al. Design of simulation module for traffic signal control at urban intersections [J]. Journal of North China University of Science and Technology (Natural Science Edition), 2018, 40(04):76-82.
[2] Sun gang. simulation research and optimization design of urban signalized intersections [J]. automotive practical technology, 2020, no 305 (02): 119-121.
[3] Lin P Q, Lei Y W, Yao K B, et al. Estimation of Intersection Queue Length and Signal Adaptive Control in Partial Network Environment [J]. Huanan Ligong Daxue Xuebao/Journal of South China University of Technology (Natural Science), 2017, 45(11):1-09.
[4] Zhang Dongming. simulation of bus priority signal control strategy based on VisVAP [J]. urban public transport, 2018, 245(11):32-35.
[5] Meneguzzz C, Gastaldi M, GiancrisstoRaro R A. Before-and-After Field Investigation of the Effects on Pollutant Emissions of Replacing a Signal-Controlled Road Intersection with a
[6] Park K M, Park Y S, Bae C O. Traffic Signal Control Simulation using Machine Vision [J]. Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, 2018, 32(7):1-7.

[7] Baldi S, Michailidis I, Ntampasi V, et al. A Simulation-Based Traffic Signal Control for Congested Urban Traffic Networks [J]. Transportation Science, 2019, 53(1): 6-20.

[8] Rida N, Mohammed O, Hasbi A. Coordinated Signal Control System in Urban Road Network [J]. International Journal of Online and Biomedical Engineering (iJOE), 2020, 16(10): 4-22.

[9] Caglar B. Hybrid Radial Basis Function Neural Networks for Urban Traffic Signal Control [J]. Journal of Engineering Research, 2020, 8(4):153-168.

[10] Malim M R, Halim F A, Rahman S. OPTIMISING TRAFFIC FLOW AT A SIGNALISED INTERSECTION USING SIMULATION [J]. MALAYSIAN JOURNAL OF COMPUTING, 2019, 4(2): 261.