MICROSCOPIC CONTROL AND OPTIMIZATION OF TRAFFIC NETWORK WITH Q-LEARNING ALGORITHM

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THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF MASTER OF ENGINEERING

**SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY
UNIVERSITI MALAYSIA SABAH**

2013

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS

JUDUL: *MICROSCOPIC CONTROL AND OPTIMIZATION OF TRAFFIC NETWORK WITH Q-LEARNING ALGORITHM*

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DEGREE : **MASTER OF ENGINEERING (ELECTRICAL AND ELECTRONICS ENGINEERING)**

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ACKNOWLEDGEMENT

I wish to express my deepest gratitude and appreciation to my supervisor, Mr. Kenneth Teo Tze Kin, for his continuous guidance to supervise me throughout the past few years. His advice, encouragement, motivation and valuable suggestions have provided me the necessary impetus to complete this research.

I express my truthful gratitude to my co-supervisor, Dr. Nurmin Bolong for her advice, support and timely suggestions for the completion of this work. I sincerely acknowledge both my supervisors for spending their valuable time in fruitful discussion on my research.

I place my sincere thanks to the supports from my labmate in Modelling, Simulation, & Computing Laboratory (mscLab) and also my friends for their cooperation and assistance. Thanks for their willingness in spending time to have wonderful discussion on my work.

My deep sense of gratitude goes to my family for their mental and financial support throughout all these years.

Chin Yit Kwong
31 October 2012

ABSTRACT

MICROSCOPIC CONTROL AND OPTIMIZATION OF TRAFFIC NETWORK WITH Q-LEARNING ALGORITHM

The main objective of this research is to optimize the traffic flow within a traffic network using microscopic level control. With the increment of on-road vehicles, modern traffic networks have more complicated topologies dealing with the higher traffic demands. Fixed-time traffic signal timing plan (FTSTP) management system and Webster's model are the most common practice used by Public Works Department of Malaysia (JKR). The current efforts made by JKR should be improved to meet the increasing traffic demands within the traffic network. In this work, Q-learning traffic signal timing plan management system (QLTSTP) is developed with the attributes of Q-learning (QL). QL is able to search for the best traffic signal timing plan through the learning process from the past experiences. In order to test the viability of the proposed system, level of vehicle in queue has been chosen as the performance indicator, whilst level of traffic flow is used to determine the traffic condition of the traffic network. QLTSTP is designed as a multi-agent system with every intersection in the developed traffic network is managed by an individual QLTSTP agent towards a mutual objective. The individual QLTSTP agent has shown better performance against the FTSTP management system with the improvement of 2.61% – 10.40% under various traffic conditions at single intersection traffic model. The performance of the multi-QLTSTP agent system is then tested in different topologies of traffic networks. The results show that there are about 2.90 % – 18.99 % of improvements in the total vehicles pass through every intersection in the traffic network for the proposed multi-QLTSP agent system. Therefore, it can be concluded that under different traffic conditions of traffic network, the proposed multi-QLTSTP agent system is able to optimize the traffic flow with the developed traffic model.

ABSTRAK

Objektif utama kajian ini adalah untuk mengoptimumkan aliran lalu lintas dalam rangkaian trafik dengan menggunakan kawalan mikroskopik. Disebabkan oleh peningkatan kenderaan atas jalan, rangkaian trafik kini mempunyai topologi yang lebih rumit untuk memenuhi permintaan trafik yang lebih tinggi. Sistem pengurusan isyarat tetap trafik (FTSTP) dan model Webster adalah cara paling umum yang diamalkan oleh Jabatan Kerja Raya Malaysia (JKR). Usaha-usaha sekarang yang dibuat oleh (JKR) perlu dipertingkatkan untuk memenuhi permintaan trafik yang semakin tinggi dalam rangkaian trafik. Dalam kajian ini, pengurusan pelan masa isyarat trafik Q-pembelajaran (QLTSTP) akan dibinakan dengan atribut-atribut Q-pembelajaran (QL). QL merupakan kaedah yang mampu mencari pelan masa isyarat trafik yang terbaik berdasarkan keupayaan pembelajaran melalui pengalamannya. Dalam usaha untuk menguji daya sistem yang dicadangkan, tahap kenderaan dalam barisan telah dipilih sebagai penunjuk prestasi, manakala kapasiti tahap aliran trafik digunakan untuk menentukan keadaan lalu lintas dalam rangkaian trafik. QLTSTP telah direka sebagai sistem berbilang egen, di mana setiap persimpangan dalan rangkaian trafik akan diuruskan oleh sistem QLTSTP yang individu untuk mencapai matlamat bersama. Egen individu QLTSTP telah menunjukkan pretasi yang lebih baik daripada sistem pengurusan FTSTP dengan peningkatan dari 2.61% hingga 10.40% di bawah keadaan lalu lintas yang berbeza di model persimpangan trafik tunggal. Pencapaian sistem egen multi-QLTSTP kemudian dikajikan dengan topologi rangkaian trafik yang berlainan. Keputusan simulasi menunjukkan bahawa terdapat 2.90% - 18.99% peningkatan dalam jumlah kenderaan yang melalui semua persimpangan dalam rangkaian trafik untuk ejen sistem multi-QLTSTP yang dicadangkan. Oleh itu, kesimpulan boleh dibuat bahawa di bawah keadaan lalu lintas yang berlainan rangkaian trafik, ejen multi-QLTSTP canggih yang dicadangkan mampu mengoptimumkan aliran trafik dengan model trafik yang dibentukkan.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CS1	Case 1
CS2	Case 2
GPS	Global positioning system
FTSTP	Fixed-time traffic signal timing plan
INT A	Intersection A
INT B	Intersection B
INT C	Intersection C
ITS	Intelligent transportation system
JKR	Public Works Department of Malaysia
pcu	Passenger car unit
QL	Q-learning
QLTSTP	Q-learning based traffic signal timing plan
SCOOT	Split, Cycle, Offset Optimization Technique
TP1	Topology 1
TP2	Topology 2
TSTP	Traffic signal timing plan
V2I	Vehicles to infrastructure
V2V	Vehicles to vehicles

LIST OF SYMBOLS

α	Learning rate of QL
ε	Greedy probability
γ	Discount factor of QL
$\mathbb{Q}_i$	Numbers of vehicle in queue
$\mathbb{Q}max$	Maximum vehicles in queue
a	Action of QL
C	Cycle length of the intersection
$Cmax$	Maximum cycle length
d_{AB}	Distant of INT A and INT B
e_i	Extended effective green
f_i	Actual flow rate into the intersection i
F_k^i	Traffic outflow for the link i at the intersection k
$Ftotal^{source,destination}$	Sum of the traffic flow from each traffic links at the adjacent traffic intersection
g_i	Effective green time of phase i
G_i	Green signal duration of phase i
l_i	Start-up lost time due to the reaction delay by the drivers
L	Total lost time in the cycle
m	Numbers of rows in Q-table
n	Numbers of columns in Q-table
$p_k^{i,j}$	Proportional constant for the traffic flow from link i to link j at the intersection k
pcu/h	Passenger car unit per hour
q_{mn}	Q-value of nth action for mth states

$Q(s,a)_i$	Q-value
$Q(s',a')$	Q-value (future)
$R(s,a)_i$	Reward function of QL
s	States of QL
S	Saturation flow
S_{AB}	Traffic flow from A to B
T_{AB}	Time travel from A to B
V_{AB}	Average travel velocity of traffic flow
veh/h	Vehicles per hour
w_i	Maximum saturation flow rate
X_i	Flow rate to capacity ratio for intersection i
y_i	Average traffic outflow from the intersection link i
Y_i	Ratio of traffic flow to saturation flow for every phase i
$Z^{j,i}$	Traffic flow rate from intersection j into i

CHAPTER 1

INTRODUCTION

1.1 Overview of Traffic Network

Urban area is a large coverage area with high population where it is covered with a high degree of complexity traffic network, which is formed with multiple intersections in the urban area. Traffic network holds an important role in the development of the civilizations, as it serves as the communication or travel linkage between places. Using analogous description, traffic network can be visualized as the blood vessels network in the human body. The travelling blood cells within the blood vessels network are representing the travelling vehicles in the traffic network. In fact the human dropping off in the various spot of the traffic network can be represented by the nutrition or oxygen carried by the blood cell. But the traffic network is an open environment, where any traffic flows outside can enter into the network. Thus, the traffic flow within the traffic network is dynamic and unpredictable.

The traffic flow conditions nowadays are getting more saturated as compared to several years ago due to the obvious increment of the on-road vehicles. New roads with more lanes have to be built to increase the capacity of the current traffic networks. However, due to the rapid development of most of the major cities, the land available for the constructions of the new roads is limited. As constructions of the new roads are no longer an option for the city planner, the optimization of the smoothness in the traffic network has became a challenging task. When the traffic demands have exceeded the traffic capacity of the traffic network, traffic congestion will start to occur.

The cost of traffic congestion is not limited to the time lost during the travelling, but the consequences of traffic congestions may be larger than one's imagination. Besides the numerous minutes and hours of time loss in the process of waiting in the middle of the traffic congestion, traffic congestion has also caused the waste of fuel. This is because idle vehicles during the traffic congestions still consume fuel; the situation is worsened when the vehicles are releasing polluted gas at the same time. Thus, traffic congestions are not only wasting the road users' precious time, but also contributing to the consumption of more petrol as well as the air pollution. The traffic-related air pollution will affect the development of asthmatic/allergic symptoms and respiratory infections in the population (Brauer, 2002). Noise pollution from the traffic congestions is also notified from the engines of vehicles (Stoilova and Stoilov, 1998; Steele, 2001). Lastly, traffic congestions slow down the deliveries of daily supplements, logistics and trades which will cause the raise in the living cost of the people in the end. Thus, the necessity of developing traffic flow control and optimization system is crucial.

1.2 Traffic Flow Control and Optimization

Various traffic controls have been used at the current traffic network to control the traffic flow's fluency. The uses of simple traffic controller like road signs until the electronic traffic controller such as traffic lights systems have been practiced in the traffic networks all around the world (Garber and Hoel, 2010). In Kota Kinabalu, the common traffic controllers used in the traffic network are the road signs, traffic lights, and lastly road infrastructure such as, roundabout and flyovers. However, as the increasing traffic flows in Kota Kinabalu has exceeded the maximum capacity of the current traffic networks, traffic congestions have occurred more often nowadays.

The traffic flow control and optimization are mostly carried out with the traffic lights system nowadays. Traffic lights system has three types of control instructions basically, they are the red signals, green signal and the amber signals. Variants of traffic lights signals can be derived from the basic signals mentioned. For example, there are modern traffic lights system which is integrated with time counter showing the remaining red signals and green signals. The existence of the amber or the yellow signal can be ceased by using the blinking of green signal. There are also traffic signals that show simple animations, mostly for the pedestrians.

Pedestrian is one of the main concerns in traffic flow control and optimization, as people demand of crossing the intersections will decrease the efficiency of the traffic control and optimization problem. The safety of the pedestrians is one of the major concerns during the development of traffic flow control and optimization system (Shende, 2010). The control of the pedestrian flow is essential to protect their safety.

Most of the traffic flow control and optimization system developed will take account of different kind of traffic parameters. The performance of the developed traffic flow control and optimization systems are analyzed by using different traffic flow parameters, such as cycle length, queue length, waiting time and etc. Optimal control of traffic flow will shorten the vehicle queue length and thus reducing the waiting time of the drivers.

1.3 Scope of Work

Macroscopic traffic network model with multiple intersections will be modelled through the computations of the details traffic parameters. Traffic flow optimization within the traffic network model will be achieved through the microscopic traffic flow control and optimization of an agent at each traffic intersection model within global environment of developed traffic network model. The agents interact between each other to gather and update the information of the dynamic environment.

1.4 Research Objectives

The aim of this research is to improve the fluency of the traffic flow within the macroscopic traffic network with multiple intersections by distributing the optimum traffic signal timing plan for each intersection. The optimization of the traffic signal timing flow will be carried out with the developed Q-learning algorithm (QL). The developed Q-learning based traffic signal time plan management system (QLTSTP) will be integrated into a multi-agents system to optimize the traffic flow within the traffic network of multiple intersections. The research objective can be achieved through the following objectives:

1.4.1 To Model and Simulate the Traffic Network System

The characteristics of the traffic flow model are reviewed to have a comprehensive understanding on the traffic model. Traffic signal characteristics are also being reviewed for development of traffic lights system for the traffic model. The parameters of the traffic flow are used to model the single intersection traffic model. The characteristics of traffic phase, cycle length, amber signal, green signal and the red signal are implemented into the developed traffic lights system. The verification of the traffic model is done by comparing the practical collected data. The last step in this traffic modeling process is to develop the macroscopic multiple intersections traffic model.

1.4.2 To Design and Develop the Q-Learning Algorithm

QL has been chosen to be the advance algorithm in this research. The characteristic of the QL parameters are reviewed and studied for the detail insight of the algorithm. The QL's elements will be determined according the traffic network characteristics. Actions of the QL will be the green signal distribution, while the states of the QL will be the level of vehicles in queue. Level of the vehicles in queue will be defined with the traffic flow characteristic reviewed. The developed QL will then be configured into the multi-QLTSTP agent system. The performance of the multi-QLTSTP agent system will be ascertained.

1.4.3 To Optimize and Evaluate the Developed Q-Learning based Traffic Signal Timing Plan Management System

The multi-QLTSTP agents system will be simulated in various traffic conditions with different traffic network topologies. The first topology for the simulation is a single traffic intersection model to test the performance of the developed QLTSTP. Then the multiple intersections traffic model topology will be run with the multi-QLTSTP agent system. Various traffic conditions are configured to test the performance of the developed system in different situations. Fixed-time traffic signal timing plan management using Webster's model will be compared with the developed QLTSTP. Lastly, evaluation and assessment of the developed system are carried out through the different cases of traffic conditions.

1.5 Thesis Outline

This thesis is organized as below:

Chapter One describes overview of traffic network and traffic flow optimization. Research scope of work, research aim and efforts are elaborated in this chapter while the organization of this thesis is included in the thesis outline.

Chapter Two presents the reviews of the optimization for the traffic flow in the traffic network. This chapter begins with the discussion on the types of the traffic flow control and then followed by a thorough review on the commonly enhanced traffic lights systems for the traffic control. Intelligent traffic system (ITS) is also being reviewed for the different approaches used. Past researches of the artificial intelligence methods in optimizing the traffic flow are discussed as well.

Chapter Three illustrates the work flow of the proposed QL algorithm. Analogous representation of the QL's elements and operators are presented throughout the chapter. Each element of the QL is discussed in details in this chapter. The basic operations of QL are introduced and the effects of each operator towards the learning ability are discussed.

The modelling of traffic model is discussed in Chapter Four. The mathematical equations used to represent traffic flow characteristics are derived. This chapter presents the details of the traffic intersection modelling. The simulation of the traffic lights model is revised to be implemented into the traffic intersection model. The modelling of the multiple traffic intersections model will be completed by using the single intersection model as basis.

Chapter Five illustrates the development of the QL based traffic signal timing plan management system. The detailed definitions of state-action pair and reward function of QL are discussed in this chapter. The traffic environment for the traffic simulations is defined clearly. The performances of the QLTSTP and the fixed-time traffic signal timing plan derived from Webster's model are investigated in different situations of the single intersection traffic model.

Chapter Six presents the control and optimization of the proposed multi-QLTSTP agent system. The multi-QLTSTP agent system has been developed and the environment setting of the multiple traffic intersections model is determined. Two topologies of traffic intersections model are developed for the simulations. The performances of the multi-QLTSTP agent system are tested under various traffic conditions at different topologies of the traffic network. The performances of multi-QLTSTP agent system are compared to the fixed-time traffic signal timing plan management system.

Finally, the conclusions, the achievements and future works have been listed in Chapter Seven.

CHAPTER 2

REVIEW OF OPTIMIZATION IN TRAFFIC SYSTEM

2.1 Overview of Traffic Control

Transportations have always been one of the fundamental keys in the development of the civilizations. In the development history of cities and countries, transportations on land have played their parts as the portal for communications, supplements, trades and even wars. Almost all of the activities in a civilization need the involvement from the transportations, ranged from walking distance to miles away. Nowadays, developments of the urban cities are getting more and more rapid and the urban areas are expanding in a fast rate. Transportations within the urban area have evolved into a complicated traffic network with countless traffic flows.

The network of the traffic has experienced the changes from a simple road between 2 places into the current traffic network with high complexity. Traffic control has also transformed itself along with the time line of the traffic network development. Traffic control has never being absent from the evolutions of the traffic network, as traffic control is needed for ensuring the fluency and smoothness of the traffic flows within the traffic network. Various kinds of traffic control have been designed for the same purpose since the beginning of the traffic network's existence, but the traffic network growth has always getting ahead in the development of the traffic control system.

Traffic demands for the traffic network always grow respectively to the development of the civilizations, but the traffic network has encountered the bottleneck stage of its development. This is because the availability of landscapes in the traffic network development has been reduced dramatically due to the development of the urban city. This is why traffic control is always needed in the traffic network as the demands towards the traffic network are always exceeds the