

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

# **Applying Matsuoka Neuronal Oscillator in Traffic Light Control of Intersections**

A thesis presented in partial fulfillment of the  
requirements of the degree of

Master of Engineering  
In  
Mechatronics

At  
Massey University,  
Auckland, New Zealand

Kuo-Chun Lin

2009

## **Abstract**

The objective of this thesis is to implement Matsuoka Oscillators into a traffic control system at an isolated intersection in order to allocate the duration of green time depends on the dynamic traffic demands. The oscillator is a model of central pattern generators (CPG) which has been successfully used in various humanoid robotic applications. A Matsuoka Oscillator was chosen in this project because of its stable and predictable rhythmic outputs. In this thesis, the inputs of a Matsuoka Oscillator are the number of vehicles, and the outputs of the model are the duration of green time in the next phase. The purpose of this thesis is to study how the unbalanced traffic demand conditions affect the control system with Matsuoka Oscillators. The results of this research are compared with the fixed time control system. The expectation of this thesis is to make the time interval more fixable and reduce the delay time in order to balance the traffic condition at the isolated traffic intersection.

## **Acknowledgements**

I would like to express my deepest gratitude and sincerest appreciation to the advisors Dr. Johan Potgieter, Prof. Peter Xu and Dr. Fakhrul Alam for supervision, enthusiastic guidance and continuous encouragement throughout the course of study.

Gratitude is also expressed to the staffs of Auckland Traffic Management Unit for their help and support.

I am also thankful to his friends Van C. Pham and Aeron Yu for assisting in many ways.

Finally I owe a special dept of thanks to my family members who have been behind all his achievements in life.

## Table of contents

LIST OF FIGURES.....	6
LIST OF TABLES.....	10
CHPATER 1 Introduction.....	12
1.1 Background of intersection problems.....	12
1.2 Adaptive signal control.....	13
1.3 Matsuoka Oscillator.....	13
1.4 Objective of the thesis.....	14
CHPATER 2 Literature review.....	15
2.1 Introduction.....	15
2.2 Intersection traffic signal control.....	15
2.3 Optimization methods for adaptive signal control.....	16
2.3.1 SCOOT.....	18
2.3.2 SCATS.....	19
2.3.3 RHODES.....	20
2.3.4 OPAC.....	21
2.3.5 LA-ATCS.....	22
2.4 Other of methods for signalized intersection.....	22
2.4.1 Fuzzy logic method.....	22
2.4.2 Linear systems control technique.....	24
2.4.3 Simulation optimization.....	27
2.5 Matsuoka Oscillator.....	29
2.5.1 Introduction.....	29
2.5.2 The example and application of using Matsuoka Oscillator.....	31
2.6 Summary of literature review.....	32
CHAPTER 3 Matsuoka Oscillators for a two-phase isolated intersection .....	33
3.1 Introduction.....	33
3.2 Formulation and structure of Matsuoka Oscillator.....	34
3.3 Designing the controller.....	35
3.3.1 Graphic User Interface.....	35
3.3.2 Analysis.....	36
3.3.3 Calibration of Matsuoka Oscillator.....	40
3.3.4 Initialization of external inputs of Matsuoka Oscillator.....	44
3.3.5 Green extension time.....	45
3.4 The structure of traffic system controller.....	46
3.5 The procedure of control system.....	47
3.6 Simulation.....	49
3.6.1 AIMSUN v.6.....	49
3.6.2 Calibration of the AINSUM Environment.....	52
3.7 Analysis.....	53
3.7.1 Different total traffic demand.....	53
3.7.1.1 Inputs and outputs analysis.....	56
3.7.1.2 Comparison of traffic performance.....	58
3.7.1.2 Summary.....	60
3.7.2 Unbalanced traffic demand.....	61
3.7.2.1 Input and output analysis.....	64
3.7.2.2 Comparison of delay time on each band.....	66

3.7.2.3 Comparison of traffic performance.....	69
3.7.2.4 Summary.....	71
CHAPTER 4 Matsuoka Oscillators for a four-phase isolated intersection.....	72
4.1 Introduction.....	72
4.2 Calibration and analysis.....	73
4.3 The structure of the control system.....	77
4.4 The procedure of control system.....	78
4.5 Calibration of the traffic environment.....	81
4.6 Analysis.....	82
4.6.1 Input & output analysis.....	87
4.6.2 Comparison of delay time on each band.....	90
4.6.3 Comparison of traffic performance.....	93
4.7 Summary.....	96
CHAPTER 5 Summary, discussion, and further research.....	97
5.1 Summary of the thesis.....	97
5.2 Discussion of adaptive signal system with Matsuoka Oscillator.....	98
5.2 Future research.....	99
REFERENCES.....	101
APPENDIX.....	104
APPENDIX C++ CODE OF MATSUOKA OSCILLATOR.....	105

## List of figures

Figure 2-1 the operation of SCOOT model.....	18
Figure 2-2 Rolling Horizon Concept (taken from Gartner, 1983).....	21
Figure 2-3 the membership function of input variable. (Taken from Haijun, Lingxi, Rui, and Feiyue, 2002).....	23
Figure 2-4 the membership function of output variable. (Taken from Haijun, Lingxi, Rui, and Feiyue, 2002).....	23
Figure 2-5 Structure of Intersection Signal Feedback Controller (Taken from Wann-Ming, Jayakrishnan, Michael, 1995).....	26
Figure 2-6 A Simplified State Dependent-Server-Vacation Signal Timing (Taken from Anthony, Anandalingam, and Nicholas, 1986).....	28
Figure 2-7 Structure of the neural oscillator. The blanked and filled dots represent excitatory and inhibitory synapses.....	29
Figure 2-8 the oscillation is generated by the model in the absence of external input. (Taken from <a href="http://www.brain.kyutech.ac.jp/~matsuoka/oscillator_English.html">http://www.brain.kyutech.ac.jp/~matsuoka/oscillator_English.html</a> ).....	30
Figure 2-9 System schematic. (Taken from Matthew, 1999).....	30
Figure 2-10 artificial neural oscillator schematic (Taken from Evan, Monica, and Daniel, 2008).....	31
Figure 3-1 the intersection with two phases.....	33
Figure 3-2 Matsuoka Oscillator with two neurons. (Taken from Bouhet, Cambonie, and Nicolotto, 2007).....	34
Figure 3-3 Graphic User Interface window ((Taken from Bouhet, Cambonie, and Nicolotto,2007).....	35
Figure 3-4 the stationary periodic output of Matsuoka Oscillator.....	36
Figure 3-5 the time values of $T_{on}$ and period.....	36
Figure 3-6 the outputs with constant input 1 and increasing input 2.....	37
Figure 3-7 the table of fixed cycle time.....	40
Figure 3-8 the relationship between Ton 1 and Ton 2 with increasing s2 and constant s1.....	41
Figure 3-9 the difference of Ton 1 and Ton 2 (the value of input 1 is 3.0 and input 2 is increasing from 3 to 4.9).....	41

Figure 3-10 the outputs with increasing input 1 from 3 to 4.9 and decreasing input 2 from 4.9 to 3.....	43
Figure 3-11 actuated controller intervals (Taken from Carl, 1995).....	45
Figure 3-12 the structure of traffic system with two Matsuoka Oscillators.....	46
Figure 3-13 the traffic control cycle time.....	47
Figure 3-14 an insulated intersection with two phases.....	47
Figure 3-15 the relationship of input and output of MO 1 in phase 1.....	48
Figure 3-16 the relationship of input and output of MO 2 in phase 2.....	48
Figure 3-17 Communication between AIMSUN and other external applications (Taken from Aimsun Microsimulator API Manual Draft Version, 2008).....	50
Figure 3-18 Interaction between AIMSUN and its API (Taken from Aimsun Microsimulator API Manual Draft Version, 2008).....	51
Figure 3-19 the simulated isolated intersection with same traffic volume scenario.....	53
Figure 3-20 the average inputs of Matsuoka Oscillator 1 with different total traffic demands.....	56
Figure 3-21 the average inputs of Matsuoka Oscillator 2 with different total traffic demands.....	56
Figure 3-22 the average green time in phase 1 and phase 2 with different total traffic demand scenarios.....	57
Figure 3-23 comparison of total travel time (Matsuoka model v.s. Fixed time control).....	59
Figure 3-24 comparison of delay time (Matsuoka model v.s. Fixed time control).....	59
Figure 3-25 comparison of flow (Matsuoka model v.s. Fixed time control).....	59
Figure 3-26 unbalance traffic demand scenario with increasing travel volume on the EB.....	61
Figure 3-27 the average inputs of Matsuoka Oscillator 1 with unbalanced traffic demands.....	64
Figure 3-28 the average inputs of Matsuoka Oscillator 2 with unbalanced traffic demands.....	64
Figure 3-29 the average green time in phase 1 and phase 2 with different total traffic demand scenarios.....	65
Figure 3-30 Matsuoka v.s. fixed time (Delay time on NB).....	67
Figure 3-31 Matsuoka v.s. fixed time (Delay time on SB).....	67
Figure 3-32 Matsuoka v.s. fixed time (Delay time on EB).....	67



Figure 3-33 Matsuoka v.s. fixed time (Delay time on WB).....	67
Figure 3-34 comparison of total travel time (Matsuoka model v.s. Fixed time control).....	70
Figure 3-35 comparison of delay time (Matsuoka model v.s. Fixed time control).....	70
Figure 3-36 comparison of flow (Matsuoka model v.s. Fixed time control).....	71
Figure 4-1 an isolated intersection with four phases.....	72
Figure 4-2 fixed cycle time for four signals.....	73
Figure 4-3 the relationship between output 1 and output 2 based on the increasing input 2 and constant input 1 in MO2 and MO4.....	75
Figure 4-4 difference between output 1 and output 2 in MO2 and MO4 (input 1 is constant 3 and input 2 increases from 3 to 5.1).....	75
Figure 4-5 the structure of the four-phase intersection with four Matsuoka Oscillators.....	77
Figure 4-6 the graph of phase 1 (Matsuoka Oscillator 1 is implemented).....	78
Figure 4-7 the graph of phase 2 (Matsuoka Oscillator 2 is implemented).....	79
Figure 4-8 the graph of phase 3 (Matsuoka Oscillator 3 is implemented).....	79
Figure 4-9 the graph of phase 4 (Matsuoka Oscillator 4 is implemented).....	80
Figure 4-10 an isolated intersection with an unbalanced traffic demand scenario.....	82
Figure 4-11 the average input 1 and input 2 in MO1.....	87
Figure 4-12 the average output 1 in MO1.....	87
Figure 4-13 the average input 3 and input 4 in MO2.....	87
Figure 4-14 the average output 3 in MO2.....	87
Figure 4-15 the average input 5 and input 6 in MO3.....	88
Figure 4-16 the average output 5 in MO3.....	88
Figure 4-17 the average input 7 and input 8 in MO4.....	88
Figure 4-18 the average output 7 in MO4.....	88
Figure 4-19 the comparison of green time in each phase.....	89
Figure 4-20 Matsuoka v.s. fixed time (Delay time on NB).....	91
Figure 4-21 Matsuoka v.s. fixed time (Delay time on SB).....	91
Figure 4-22 Matsuoka v.s. fixed time (Delay time on WB).....	91
Figure 4-23 Matsuoka v.s. fixed time (Delay time on EB).....	91
Figure 4-24 comparison of total travel time (Matsuoka model v.s. Fixed time control).....	94

Figure 4-25 comparison of delay time (Matsuoka model v.s. Fixed time control).....95  
Figure 4-26 comparison of flow (Matsuoka model v.s. Fixed time control).....95

## List of tables

Table 2-1 summary of adaptive control system (taken from Bhargava et al, 2003).....	17
Table 2-2 the performance of two control methods (Taken from Gao et al, 2002).....	24
Table 3-1 the relationship of outputs ( $T_{on} 1$ and $T_{on} 2$ ) in Matsuoka Oscillator with constant input 1 (3.0) and increasing input 2.....	39
Table 3-2 the relationship of outputs ( $T_{on} 1$ and $T_{on} 2$ ) in Matsuoka Oscillator with increasing input 1 (from 3.0 to 4.9) and decreasing input 2 (from 4.9 to 3.0).....	42
Table 3-3 the number of vehicles presents in inputs of Matsuoka Oscillator.....	44
Table 3-4 Data requirements for calibrating the AINSUM environment.....	52
Table 3-5 traffic scenarios with same traffic volume on each band but increasing total traffic demands.....	54
Table 3-6 the inputs and outputs of Matsuoka model with same traffic volume on each band but different total traffic demand after the simulation.....	55
Table 3-7 the comparison of performance between control system with Matsuoka Oscillator and fixed time control system.....	58
Table 3-8 unbalanced traffic demand scenarios with increasing traffic volume on EB.....	62
Table 3-9 the table of inputs and outputs in Matsuoka model in unbalanced traffic demand scenarios after the simulation.....	63
Table 3-10 the comparison of average delay time (vehicle/second) on each band between Matsuoka model and fixed time control system.....	66
Table 3-11 the comparison of performance between control system with Matsuoka Oscillator and fixed time control system in unbalanced traffic demand scenarios.....	69
Table 4-1 the relationship of outputs in MO2 and MO4 with constant input 1 and increasing input 2.....	74
Table 4-2 the number of vehicles presents in the inputs of MO2 and MO4.....	76
Table 4-3 the relationship of Matsuoka Oscillators operates in four phases.....	80
Table 4-4 Data requirements for calibrating the AINSUM environment.....	81
Table 4-5 unbalanced traffic demand scenarios with increasing traffic volume on EB &WB.....	83

Table 4-6 the table of inputs and outputs in Matsuoka model in unbalanced traffic demand scenarios after the simulation.....	84
Table 4-7 the comparison of average delay time (vehicle/second) on each band between Matsuoka model and fixed time control system.....	90
Table 4-8 the comparison of traffic performance between control system with Matsuoka Oscillator and fixed time control system.....	93