Fuzzy Intelligent Traffic Control System

Hamid Mir-Mohammad Sadeghi

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Applied Mathematics and Computer Science

Eastern Mediterranean University
June 2010
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director (a)

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Applied Mathematics and Computer Science.

Prof. Dr. Agamirza Bashirov
Chair, Department of Mathematics

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Applied Mathematics and Computer Science.

Assoc. Prof. Dr. Rashad Aliyev
Supervisor

Examining Committee

1. Prof. Dr. Nazım Mahmudov
2. Assoc. Prof. Dr. Rashad Aliyev
3. Asst. Prof. Dr. Mehmet Bozer

ABSTRACT

The aim of this thesis is to develop the fuzzy intelligent traffic control system for the optimal controlling of the traffic flow at the traffic intersections. The proposed fuzzy control system is used to effectively manage the urban traffic junction of the intersections of the city Famagusta (Gazimagusa), North Cyprus.

The importance of the proposed fuzzy intelligent traffic control system consists in consideration of uncertainty and vagueness of information about the values of the input and output parameters of the system. Using the input parameters and based on the inferences from the fuzzy rules, the fuzzy traffic controller decides how to adjust the extension time of the green phase of traffic lights.

The computer simulation is carried out using Matlab software. The optimal extension time of the green phase is determined using the Mamdani inference engine.

The effectiveness of the fuzzy traffic controller with four input parameters is explained.

Keywords: Fuzzy System, Traffic Control, Fuzzy Logic Controller.

ÖZ

Bu tezin amacı yol kavşağında trafik akışını optimal kontrol etmek için bulanık trafik sistemini geliştirmektir.

Önerilen bulanık kontrol sisteminin kullanılmasında amac Kuzey Kıbrıs'ın Gazimağusa şehrinde kentsel trafik kavşağını etkili yönetmekdir.

Önerilen bulanık trafik sisteminin önemli özelliği sistemin giriş ve çıkış parametre değerlerinin belirsizlik halinde başarıyla kullanılabilmesinden ibaretdir. Bulanık trafik kontrol sistemi giriş parametrelerini kullanarak ve bulanık kurallardan elde edilen neticeye dayanarak trafik ışıklarının yeşil fazının ayarlanması konusunda karar veriyor.

Matlab yazılımını kullanarak bilgisayar simulyasyonu oluşturulmaktadır. Trafik ışıklarının yeşil fazının optimal ayarlanması için Mamdani sonuc çıkarma yöntemi kullanılmaktadır.

Dört parametreli bulanık trafik kontrollerin etkinliği açıklanıyor.

Anahtar kelimeler: Bulanık Sistem, Trafik Kontrol, Bulanık Mantık Kontroller.

This master thesis is dedicated to my family.

AKNOWLEDGMENTS

I am deeply grateful to my supervisor, Associate Professor, Dr. Rashad Aliyev, for his guidance and permanent support during the preparation of my master thesis.

I would like to express the deepest appreciations to my parents and brothers who always have been the best supporters of me in my whole life:

My father, Professor, Dr. Javad Mir-Mohammad Sadeghi, has always been providing any kind of help in all the steps through my life.

My mother, Ashraf Tadayon, whom I owe my gratitude, has done more than a mother can do for her son.

My brother, Ali Mir Mohammad Sadeghi, was an unbelievable kind and intelligent person. He always helped all the people around him as a brother with high skills.

My brother, Dr. Amir Mir Mohammad Sadeghi, is the guidance of my life because he has been spending every minute of his life in the best way.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

The concept of Fuzzy Logic (FL) was proposed by Professor Lotfi Zadeh in 1965. Zadeh's intention of proposing fuzzy logic was to use the uncertain information rather than precise numerical ones. For instance, when we have some weather forecasting information which is not precise, we can foretell the weather situation with a relatively logic, this is where fuzzy logic can help us using these data for a simple prediction.

Fuzzy logic is dealing with imprecision and vagueness of information and is in contrast with crisp logic. In crisp logic we only have two options or situations which cause a Boolean environment. For instance, when we want to give some information about the height of a person, we only have two options of being tall or short, or in some situations we have only true or false or generally speaking, zero or one. Fuzzy logic is very good in uncertainty, i.e. when we do not have certain information about the situation or problem and still we need to have an inference or solution, we can use fuzzy logic to generate these deductions on basic probabilities.

This is a wrong belief that probability theory can solve any kind of uncertainty problem. In this theory we are looking for the probability of the occurrence of an event in contrast to fuzzy logic which deals with the relativity value of the event. The reason we cannot use probability theory to solve such problems is that modeling such situation is not compatible with human decision processes. In fuzzy logic, for example, we are dealing with voltage of equipment, different statements and linguistic variables such as “very high voltage”, “high voltage” and “normal voltage”. A voltage can belong to the very high voltage set or even other statements but with different relativity value, this value is between 0 and 1, and it is called membership function or degree of truth.

Membership functions can have different kinds of shape. The most common ones are triangular, trapezoids and bell curves. The processing stage is based on a group of rules represented in the form of IF-THEN statements. For instance, suppose that the height of man is represented as:

IF (180<h(x)<190) Then (the man is “tall”)

Here h(x) is a function that shows the height of man represented by x in cm. This rule uses the truth value of the “height of man” input, which is some truth value of (180<h(x)<190), to generate a result in the fuzzy set to categorize the height of man for output, that is the value of “tall”. This result is used with the results of other rules to finally generate the output.

In different areas of science some extensions of fuzzy logic are used, such as Łukasiewicz fuzzy logic, Gödel fuzzy logic, and product fuzzy logic [1].

In 70's the belief of Professor Zadeh was that a control system could have the high capability of adaptive control with non precise input information.

The mathematical models are used in the process of designing the conventional control system, and these models are described by differential equations. The fuzzy control system uses heuristic nature of human knowledge.

Fuzzy controllers are based on fuzzy logic theory, and are successfully applied for many industrial problems such as robotics, wash machine, oil-refinery plants, signal processing and etc.

Fuzzy controllers have not been used widely for traffic problems. These controllers are very useful in complex traffic junctions and emergency conditions. For instance, when police car, fire engine or ambulance has particular destination to reach, there are several different routes to reach there, but as long as timing is an important issue, in such cases we are looking for a way to minimize the time. There are different factors affecting the time needed to get to the destination point such as density of traffic, size of streets or roads and etc.

By using heuristic searching algorithms to find the best path and adding fuzzy factors such as amount of road traffic and traffic light sequences, we can find the best direction.

Fuzzy control system consists of three stages [1]: the input stage, the processing stage, and the output stage. In the input stage the data from sensors, switches, and cameras are collected to define the appropriate membership functions. The processing stage is used to define the appropriate rule to generate a result for each, and to combine the results of rules. In output stage the result is again converted back to control output value.

Chapter 2

STATE OF THE ART OF FUZZY INTELLIGENT TRAFFIC CONTROL SYSTEM

2.1 Review of existing literature on fuzzy intelligent traffic control system

In [2] the fuzzy control system in urban intersection is tested. The ITCARI fuzzy control system for arterial intersection in the city is developed. The simulation indicates that this system can be successfully used for high safety and efficiency demands of the high-class arterial roads.

Paper [3] is about fuzzy control framework that evaluates congestion degree and the fuzzy control algorithm to be applied on intersection to eliminate traffic congestion diversion. The framework illustrates how to detect the volume of the traffic and control it at the same time.

The paper [4] considers the application of the discrete event, fuzzy based supervisory controller in an urban traffic problem. Three elements for controlling the urban traffic are mentioned: time varying nature of intersections, involvement of human behavior in the system and large scale distributed nature of the problem. Taking these elements into account, the novel fuzzy system is developed.

In [5] the fuzzy logic based approach to multi-objective signal control is proposed. In this research the authors develop a tool that can be used by traffic engineer to balance each objective by setting acceptability and unacceptability of thresholds for each object. By using genetic algorithm coupled to the VISSIM microscopic traffic simulator membership functions of the fuzzy logic are optimized.

There are several models for isolated signalized intersections. In [6] Fuzzy Logic Multi-phased Signal Control (FLMuSIC) model is created. This model consists of two systems that are based on fuzzy logic technology. One of these systems is used to arrange green time duration, and the other one is intended for phase sequences using traffic volumes. The two other models are traffic-actuated simulation and the aaSIDRA vehicle actuated models. These two models are compared with FLMuSIC. The results show that the performance of FLMuSIC is better than the other two models.

Fuzzy logic based delay estimation system is modeled and proposed in [7]. In this paper the fuzzy logic based delay estimation combines the technical (such as traffic demand, signal control etc.) and the nontechnical factors (such as weather). It is mentioned that the effectiveness of the proposed system is that it is adaptive to changing environment. Simulation and testing of the fuzzy system show that the proposed model is a better approach for the improvement of intersection delay estimation.

The fuzzy logic based traffic junction signal controller (FTJSC) is discussed in [8]. The main characteristics of the proposed fuzzy controller are different input variables, lower inference frequency, fewer control rules, and correlating each junction with others. The results confirm the high performance of the proposed FTJSC.

In [9] the adaptive neuro-fuzzy inference system (ANFIS) is used for prediction of the traffic volume. The Self Organizing and Hopfield neural networks are combined to optimize each phase of the traffic signals.

In [10] proposed fuzzy logic controller is used to park a truck anywhere on the x – axis without the consideration of the mathematical model of the system. Comparison results between the new designed controller and the existing controllers show that the proposed controller significantly improves the control performance for making the parking process faster.

[11] considers the automatic method for the development of the fuzzy logic multiple controllers for the automated car parking. These controllers use multi-objective evolutionary optimization requiring three important factors such as encoding scheme, design of multi-objective evaluation criteria, and design of proper evolutionary operations.

The [12] proposed systems are intended for the parking reservation and parking revenue management. The intelligent parking control system is based on the combination of two techniques: fuzzy logic and integer programming. The proposed control system makes an online decision whether to give a parking permission to a new driver or not. The authors make intelligent parking system by using different kinds of vehicle arrivals to be able to learn from parking strategies and then creating new rules for assuming the future traffic arrival patterns.

[13] considers an application of diffuse systems in traffic lights. Three proposals of diffuse control design are formulated to have the optimal traffic flow.

The authors of the paper [14] study an urban traffic to optimize the time duration of traffic lights. The fuzzy algorithm based on cellular automata is discussed. Some parameters such as different times of a day, density of vehicles of street and number of shopping centers have significant affects on the traffic of streets. Three leveled fuzzy system is proposed to overcome some limitations with traffic control.

In [15] the electrosensitive traffic light using fuzzy look up table method is suggested. This method makes it possible to reduce the vehicle waiting time, and to increase the speed of vehicles. Computer simulation shows that the average vehicle waiting time for considering passing vehicle length for optimal traffic cycle is better than the fixed signal method.

In [16] the authors develop an intelligent traffic light control regime. Generic Self-organizing Fuzzy Neural Network (GenSoFNN), Pseudo Outer Product based Fuzzy Neural Network (POPFNN), Fuzzy Adaptive Learning Control Network (Falcon), and Multilayer Perceptrons (MLP) architectures are proposed. Using these architectures, it is possible to create different traffic condition at simple traffic light intersection and complex traffic intersection.

One way to predict traffic flows in an urban street network is Fuzzy-Neural Model (FNM) which is discussed in [17]. Gate Network (GN) and Expert Network (EN) are two modules of FNM. Using these two modules, it is possible to simulate the clusters with their characteristics to model the relationship within each of these clusters.

In [18] proposed neuro-fuzzy traffic controller uses “if-then” linguistic rules. The reinforcement learning algorithm of the neural network is used for assigning credits for successful system behavior.

In [19] the fuzzy controller is suggested to estimate the driver response behavior. The experimental results show the importance of the behavior-consistent method.

In [20] the fuzzy logic technology based system is applied to detect an incident at traffic intersection. The integral component is used for clustering technique to collect data from different location and make it a single data set to improve fuzzy logic for incident detection. Another component is also introduced in this paper that can be used to determine the possibility of an incident.

[21] presents a control algorithm for a platoon of vehicles which is related to intelligent vehicle highway systems (IVHS). The suggested control algorithm is used for both headway and velocity controllers. This algorithm is successfully used for the vehicles with different performances.

2.2 State of the problem

The difficulty of the traffic control process is related with uncertain and nondeterministic nature of information about the parameters of traffic, but the classical approaches ignore the uncertainty and fuzziness of parameters of traffic control. Moreover, there is no system that overcomes many limitations of existing approaches to meet all the above mentioned requirements to get as much efficiency from the using of control system as we desired. Therefore it is necessary to develop the fuzzy traffic control system that will work adequately according to traffic demands.

The research considered above has made a big contribution to the implementation of urban traffic control system in roadways and highways. But in most cases the conventional traffic systems cannot operate effectively in real time when we are dealing with heavy volume of road traffic. Therefore the traffic control system can be better optimized using heuristic model operating in an uncertain environment. For this reason, in this thesis we use fuzzy logic approach to control the road junction.

The thesis is organized in the following form:

In chapter 2 the importance of fuzzy traffic control system for optimal controlling of heavy traffic flow is explained. The architecture of fuzzy traffic control system is proposed. The main components of the fuzzy traffic control system and their working principles are presented. The four input parameters and the one output parameter of the fuzzy traffic controllers are presented. These parameters are represented by some linguistic variables. The graphical representation of the membership functions of input and output parameters are described.

In chapter 3 the computer simulation results of the proposed fuzzy traffic controller are presented. The simulation results are performed using Matlab software. As a case, the traffic intersection in one of the roads of the city Famagusta (Gazimagusa, North Cyprus) is studied. The Mamdani defuzzification method is used for the optimal control of extension time of green light in traffic.

CHAPTER 3

FUZZY MULTI – AGENT SYSTEM FOR TRAFFIC CONTROL

3.1 Fuzzy traffic control problem

The traffic lights are very important to optimally manage the traffic volume of vehicles in an urban intersection. The traffic lights intend to make the traffic quality better, and to keep safety of the traffic flow.

The general representation of the traffic intersection is represented in the figure 3.1.

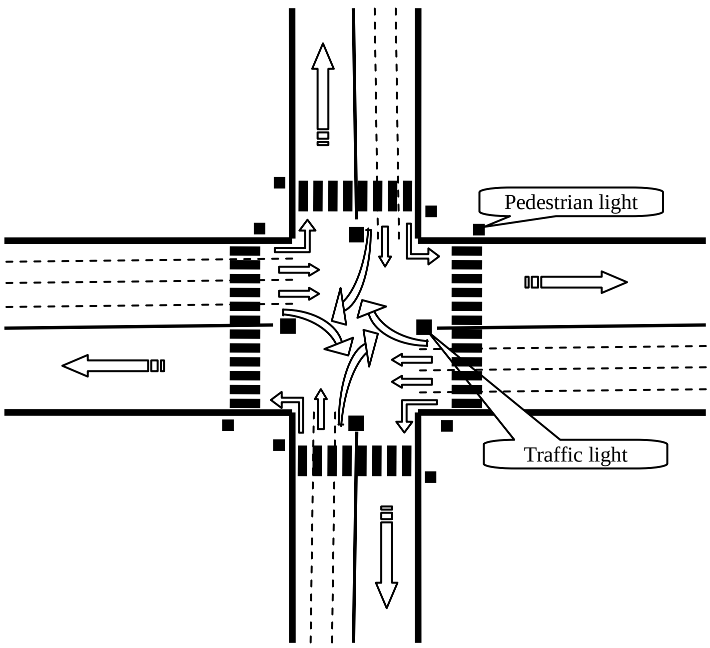
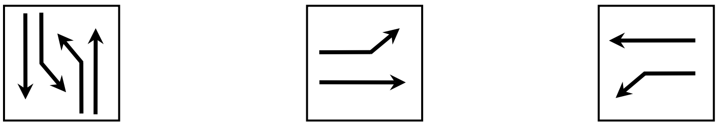


Figure 3.1 General representation of traffic intersection

In the above figure the intersection has 4 arms. The main road has four lanes and the other road has three lanes. Each lane is considered for each direction: turning left, going straight and turning right. In this model we can suppose different numbers and kinds of phases. In the figure 3.2 three phases in traffic control system are depicted.



(1) (2) (3)

Figure 3.2 Three phases in traffic control system

1. From north to south (straight), from north to east (turning), from south to north (straight) and from south to west (turning).
2. From west to east (straight), from west to north (turning).
3. From east to west (straight) and from east to south (turning).

All the vehicles can turn to the left without considering the light.

These phases can have different sequences, for instance, {1,2,3} or {1,3,2} (according to the numbers given above). By controlling these phases, the control system gains different results. On the other hand, there are different parameters referring to the controlling traffic light time.

The traffic lights normally have the fixed time for each of the red, amber, and green phases. This might be acceptable, if we are always dealing with the same density of vehicles in the intersection of the roads. But sudden heavy traffic load in the morning or evening, before or after the working hours, may create a big jam at the intersection and the fixed time of traffic phases will be inconvenient to eliminate the possible difficulties in such situations.

The significant vehicle number increment and slow development of roadways and highways lead to serious traffic junctions. Using conventional techniques is ineffective to design the controller that optimally manages the traffic conflict, because it is very difficult to consider all the aspects of the dynamic changes of the traffic, and the classical controllers couldn't take the non-linear, fuzzy, and uncertain natures of information into account which are characteristics of current traffic problems.

In this consideration, the optimal traffic control can be achieved by the elimination of congestion on roads, and minimization of delay time of the vehicles. Solving the above problems will lead to appropriate vehicle density at the traffic congestion.

Fuzzy traffic control system is a very important tool in order to have a high performance in optimal controlling of the extension time of the green phase at the intersection.

In the section 2.2 we consider the way how to establish such a kind of intelligent traffic control system.

3.2 Architecture of multi – agent system for traffic control

The structure of fuzzy traffic control system, described in figure 3.3, consists of two parts, and each of these parts includes some blocks. The first and second parts are related to Fuzzy Control System and traffic controller components, respectively.

Fuzzification, inference mechanism, knowledge base, database, defuzzification, and controlled process are the components of Fuzzy Control System [22-25].

There are four parameters used as inputs of fuzzy traffic controller to estimate the measure of traffic at the urban intersection. The input parameters of the fuzzy traffic controller are:

1. Maximum length of traffic queue in red signal (MLTQRS).
2. Arrival rate of vehicles at junction during the green signal (ARJGS).
3. Remaining time of green signal (RTGS).
4. Prediction of vehicle congestion (PVC).

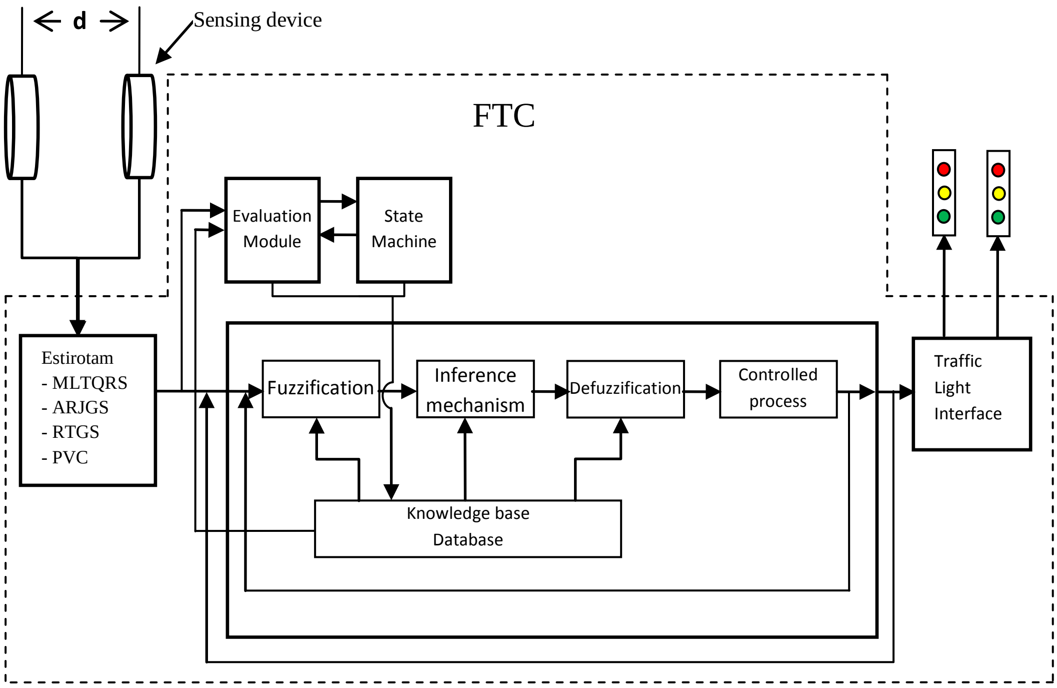


Figure 3.3 The structure of fuzzy traffic control system

Fuzzification

Fuzzification in a control system is a process of converting crisp input and output values into fuzzy form. For the realization of the fuzzification process, the knowledge base, database and membership functions are used. Input data matches the condition part of rules in knowledge base. This matching shows the degree of membership for each linguistic term that manipulates the input variable.

If the input of fuzzification part is e^*, then this signal will be converted into the form based on fuzzy set with the membership function $\mu_A(e)$ and represented with e^* [24-26]:

$$\left(e^* = \mu_A(e)\right)$$

Knowledge base

This part contains all the knowledge about the input and output fuzzy partitions. Knowledge base is the set of fuzzy control rules that are used to form rule base or rule set for a Fuzzy Logic Controller (FLC) [24]. Knowledge base is designed by using input and output variables, and also source types of fuzzy control rules.

Database

In the proposed control system, the database is used to manage the time of traffic lights used in self-organizing controller. Database modifies the general rule base and sets the best rule base for control system. Also database has the sequence of traffic light states from state machine which were followed in inference part [24-25].

Inference mechanism

This part is the kernel of fuzzy controller. The inference mechanism performs the matching process by defining the correct rules corresponding to the current situation, and finds the input of the control system, i.e. the inference mechanism takes the recommendation of the matched fuzzy rules into account to produce the fuzzy conclusion. In the next stage defuzzification block converts the fuzzy conclusion into a crisp one.

Inference mechanism involves membership functions, logical operation and IF-THEN rules. Membership function is a curve that shows each point in input space mapped to the value between 0 and 1 as output. Here 0 is false, and 1 is true and we can define the meaning of true. For instance, we suppose 1 means a heavy traffic and 0 is a light traffic. The value between these two numbers determines the ratio of heavy traffic.

In conditional statements the IF…THEN rule is described as:

IF x is A THEN y is B

There are two parts in IF…THEN rules; the first part "*x* is *A*" is called antecedent and the second part "*y* is *B*" is called consequent.

As it was mentioned in database part, database has the sequences of traffic light states. These data are used in inference part. For each phase of traffic lights there is one corresponding state. Changing the state depends on different conditions that can be given as follows: end of green period time, changing the method of controller or measure of the extension time, the condition that there is not any arriving vehicle before the green period time ends, and the special condition that the controller has received message from outside of the system as an order to lock green phase of traffic lights in order to let the emergency vehicles (ambulance, police car or fire engine) cross the intersection.

Defuzzification

Defuzzification is the inverse process of fuzzification. In this part, all the output values of the control system are converted from fuzzy form into the crisp one, because outputs cannot be described by fuzzy quantiles. There are seven different build-in methods for defuzzification: centroid, Max-membership principle, middle of maximum or mean-max membership (the average of the maximum value of the output set), weighted average method, centre of sums, centre of largest area, and first of maxima or last of maxima [25].

In this thesis we are using Mamdani inference using centroid defuzzification method represented by the center of area or the center of gravity (Figure 3.4). z^* is calculated as:

$$z^* = \int \frac{\mu_{\tilde{c}}(z) z \, dz}{\mu_{\tilde{c}}(z) dz}$$

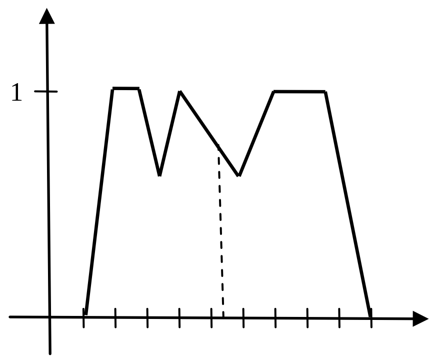


Figure 3.4 Centroid defuzzification method

Controlled process

The input and output values of the control system must always be crisp. So using defuzzification process, the membership functions of the fuzzy sets are transformed into the crisp form to be sent to the input of the controlled process.

Traffic controller components

Fuzzy control system is the engine of fuzzy traffic control. There are some other components that gather data and organize them for fuzzy control system packing: sensing devices, estimator, adaptive module, state machine and traffic light inference [22].

Sensing devices

The sensing devices are group of sensors that relate current data to each way of the intersection, for example, detection of arrival rate of vehicles with their speed, length of vehicle queue and other sensors which help the estimator part.

Estimator

The estimator uses data from sensing devices and calculates the speed of each vehicle and its time needed to cross the intersection in green phase. Estimator also calculates the length of queue and the arrival speed behind the red light.

The state machine

The state machine has the sequence of traffic light states and controls the sequences of states by inference.

Evaluation module

The evaluation module gets the information from database about each road in different hours and days. This module also gets information from estimator to evaluate the importance of each road. In every period of time, each road is labeled with the degree of importance. The degree of importance is combined with the data from state machine and the result is sent to database for optimizing the method.

The degree of importance of each road is determined using some characteristics. These characteristics are referred to the number of lanes that road has, and the traffic measure is described by the number of shops or schools, entertainments utilities, etc.

The traffic light interface

Traffic light interface includes all circuits needed for changing the state of lights according to the output taken from the fuzzy controller.

Let's consider the four input parameters of fuzzy traffic controller:

1. **MLTQRS**: This parameter refers to the length of the queue of vehicles behind the red phase. The parameter MLTQRS is represented by the linguistic variables "very small", "small", "medium", "long". For example, the triangular membership function of the linguistic variable "medium" is graphically represented in the figure 3.5.

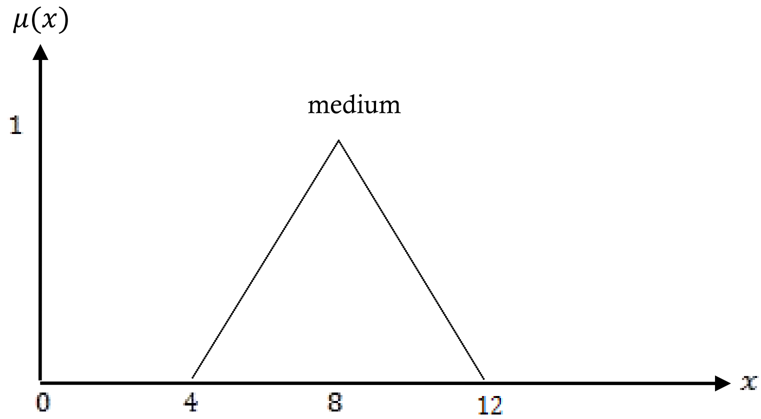


Figure 3.5 Membership function of the linguistic variable "medium" of MLTQRS

2. **ARJGS**: This parameter refers to the arrival rate of vehicles (number of vehicles per second) in green phase. The parameter ARJGS is represented by the linguistic variables "very few", "few", "moderate", "many". For example, the triangular membership function of the linguistic variable "few" of ARJGS is graphically represented in the figure 3.6.

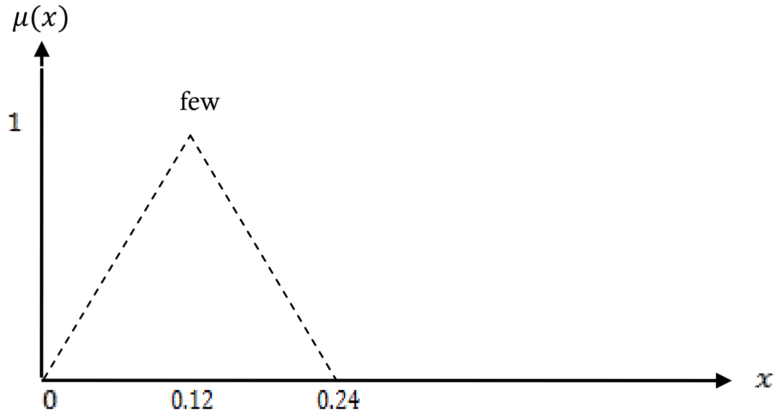


Figure 3.6 Membership function of the linguistic variable “few” of ARJGS

3. **RTGS**: This is another important input parameter of fuzzy traffic control system. This parameter estimates the remaining green time when there is no traffic. It is important to consider the remaining green time in respect to the traffic congestion for vehicles that will arrive. For instance, if the rate of vehicles arriving in green signal is too low and the remaining green time is high (for instance, with membership function μ(0.8)), then the control system should decide to decrease the green time duration. The parameter RTGS is represented by the linguistic variables “very few”, “few”, “medium”, “long”. For example, the triangular membership function of the linguistic variable “medium” of RTGS is graphically represented in the figure 3.7.

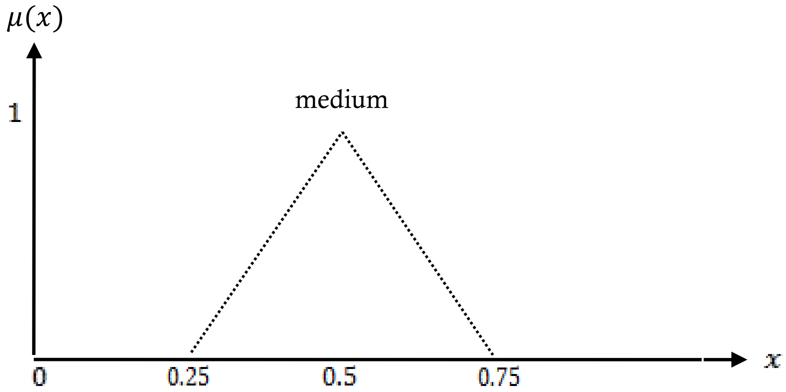


Figure 3.7 Membership function of the linguistic variable "medium" of RTGS

4. **PVC**: This parameter estimates the number of vehicles that will reach the intersection in a short period of time (for example, 10 seconds). To decide more accurately for the RTGS, it is important to know the number of vehicles (density) arriving in the above mentioned time. As we mentioned for RTGS parameter, when the arrival rate of vehicles in green phase is too low, the remaining green time is high, and the group of vehicles is near the intersection (for instance, a group of vehicles that have come from previous intersection), we can conclude that in this case the control system decides (without considering the PVC parameter) to decrease the green time by changing it to the red signal. It causes to have group of vehicles behind the red signal in a short period of time. For a better decision, we have to use PVC so that to make the control system to be able to consider this group of vehicles, and not to decide to change the green time duration, permitting the vehicles to cross the intersection. The parameter PVC is represented by the linguistic variables "few", "moderate", "many". For example, the triangular membership function of the linguistic variable "moderate" of PVC is graphically represented in the figure 3.8.

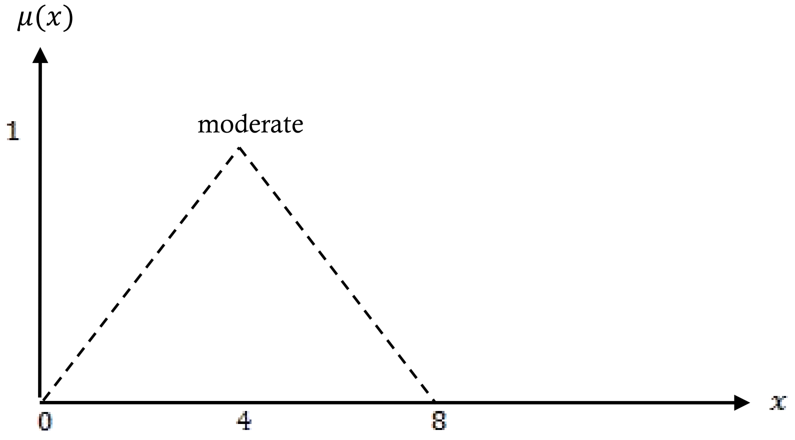


Figure 3.8 Membership function of the linguistic variable “moderate” of PVC

Figure 3.9 shows an example of road with the length of *x* (m) that is a distance between the speed estimator and the intersection. The first sensor is intended to detect the mass of vehicles, and the second sensor is used to estimate the average speed ($\bar{v}$). By using these data the control system can determine the arrival time of the mass of vehicles.

$$t = \frac{x}{\bar{v}}$$

These vehicles will arrive to the intersection in *t* seconds.

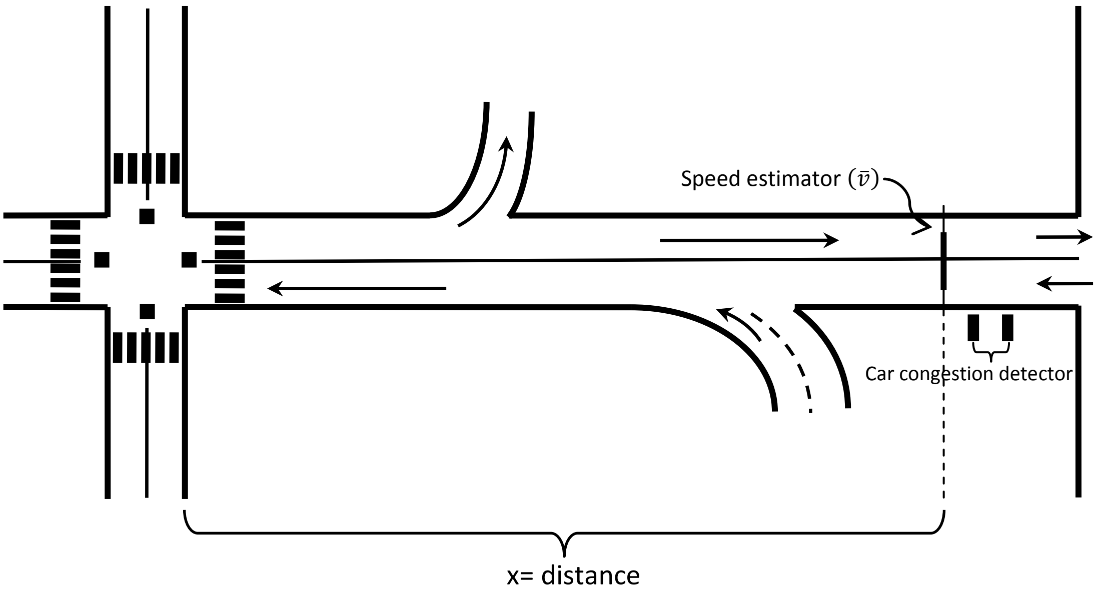


Figure 3.9 Prediction of vehicle congestion example

Extension of the green signal time is the only output of the fuzzy traffic controller. The Extension parameter is controlled according to the traffic situation. It is obvious that in a lane with many arriving vehicles the duration of green phase should be long, and when few vehicles arrive, the duration of the green phase of the traffic lights should be short. At the same time, the traffic demand on other lanes should be also taken into consideration to optimize the duration of the green phase in the intersection.

The output parameter Extension is represented by the linguistic variables “more decrease”, “decrease”, “do not change”, “increase”, “more increase”. For example, the triangular membership function of the linguistic variable “increase” of the output parameter Extension is graphically represented in the figure 3.10.

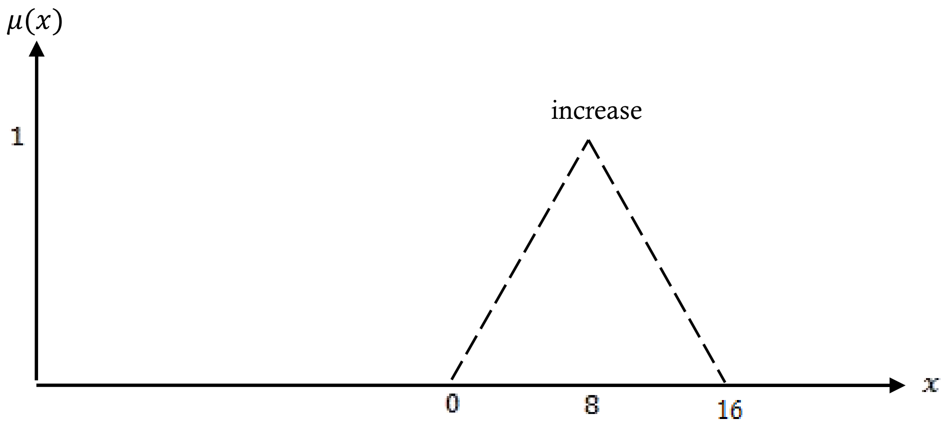


Figure 3.10 Membership function of the linguistic variable “increase” of Extension

Chapter 4

COMPUTER SIMULATION OF THE TRAFFIC CONTROL SYSTEM

4.1 Famagusta (Gazimagusa) as a case study

As a case study we use one of junctions of Famagusta (Gazimagusa) city, North Cyprus, and the fuzzy traffic controller is used for the intersection of Famagusta – Nicosia (Gazimagusa - Lefkosha) road. This road has three arms. The most important arm is turning from Nicosia road to Salamis road that is shown with the arrow in Figure 4.1.

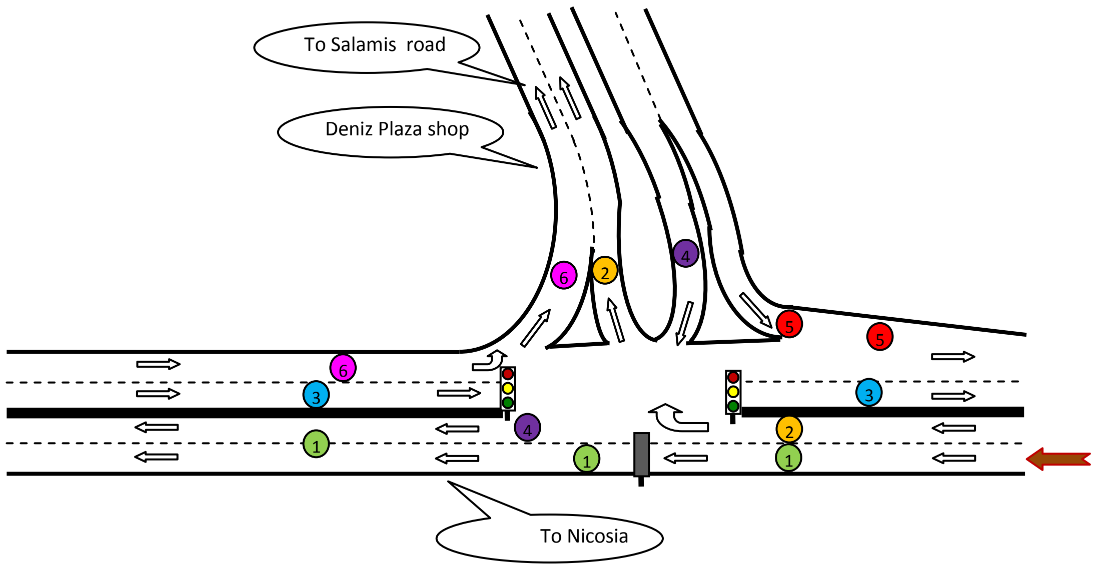


Figure 4.1 Road intersection in Famagusta city

Input parameters:

The following input parameters (in the section 3.2 we mentioned the full names of these parameters and all the linguistic variables they are represented by) of fuzzy controller and real data are used for the above road:

1. MLTQRS: Maximum length of vehicles behind red signal is up to the number of vehicles behind red signal in other ways. The time duration of red signal is 60 seconds and the length of queue of vehicles is measured in this time duration. For MLTQRS we need data of those arms that are in sequence of phases. In the table 4.1 the statistical data for the arms with numbers 2, 3 and 4 are given:

Table 4.1 Statistical data for the arms 2, 3, and 4

Next round of the sequence of phases / The number of the way	1	2	3	4	5	6	7	8
2	2	13	8	1	9	7	2	1
3	4	10	7	13	10	1	6	4
4	3	5	5	6	8	4	5	9
MLTQRS	4	13	8	13	10	7	6	9

The membership functions of the linguistic variables of the parameter MLTQRS are graphically represented in figure 4.2.

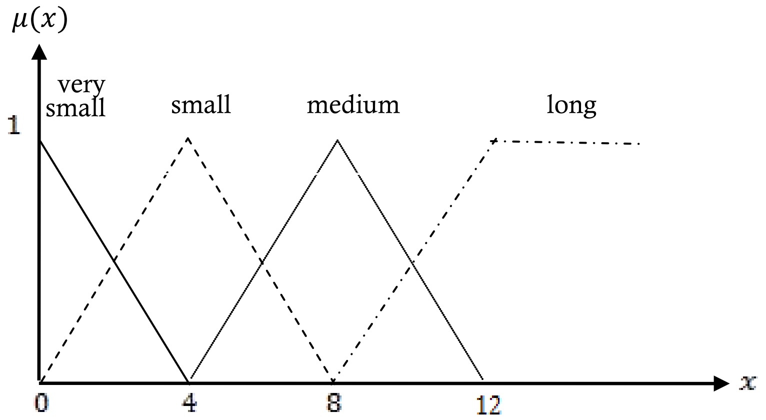


Figure 4.2 Membership functions of the parameter MLTQRS

2. **ARJGS:** In Famagusta – Nicosia road the green signal time duration is 45 seconds. The real data for ARJGS are given in the table 4.2.

Table 4.2 The real data for ARJGS

Next round of the sequence of phases	**1**	**2**	**3**	**4**	**5**	**6**
ARJGS	$\frac{9}{45}$	$\frac{16}{45}$	$\frac{12}{45}$	$\frac{14}{45}$	$\frac{11}{45}$	$\frac{9}{45}$

The membership functions of the linguistic variables of the parameter ARJGS are graphically represented in figure 4.3.

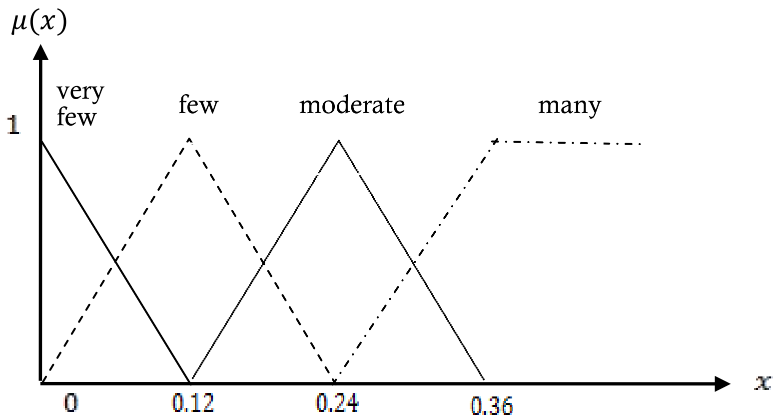


Figure 4.3 Membership functions of the parameter ARJGS

3. **RTGS:** The membership functions of the linguistic variables of the parameter RTGS are graphically represented in figure 4.4.

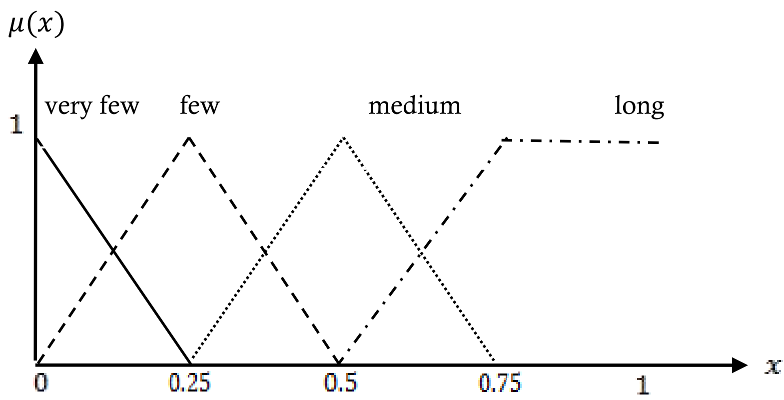


Figure 4.4 The membership functions of the parameter RTGS

4. **PVC:** The membership functions of the linguistic variables of the parameter PVC is graphically represented in figure 4.5.

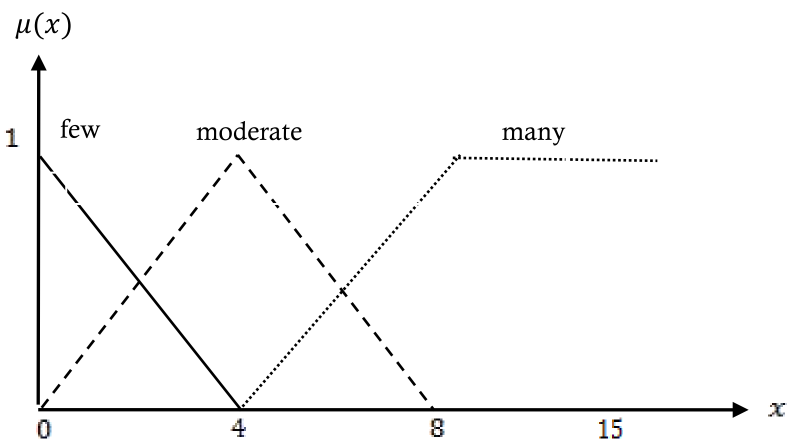


Figure 4.5 The membership functions of the parameter PVC

Output parameter:

Extension: With four input parameters, the fuzzy traffic controller has the information about the situation at the intersection, and the controller should decide how to change the duration of green phase of the traffic lights. The membership functions of the linguistic variables of the parameter **Extension** are graphically represented in figure 4.6 (the negative and positive values mean decreasing and increasing of green signal time , respectively).

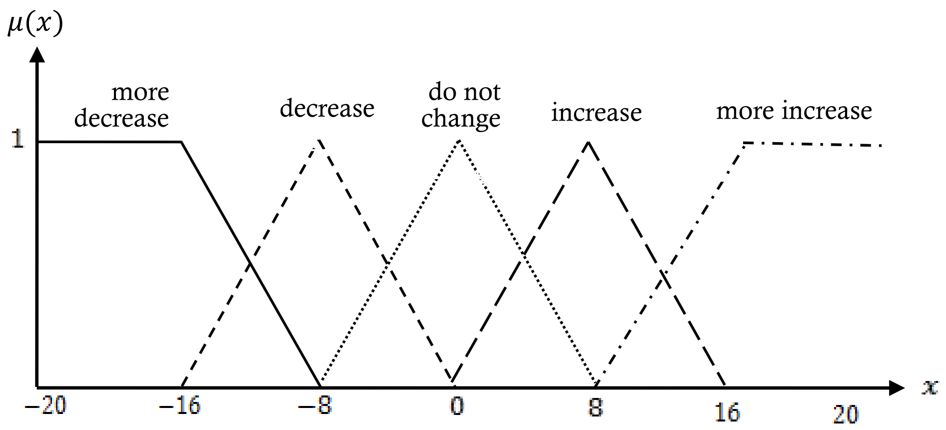


Figure 4.6 The membership functions of the parameter Extension

Figure 4.7 depicts the image of the intersection in Famagusta city (Famagusta – Nicosia road) from Google Earth.

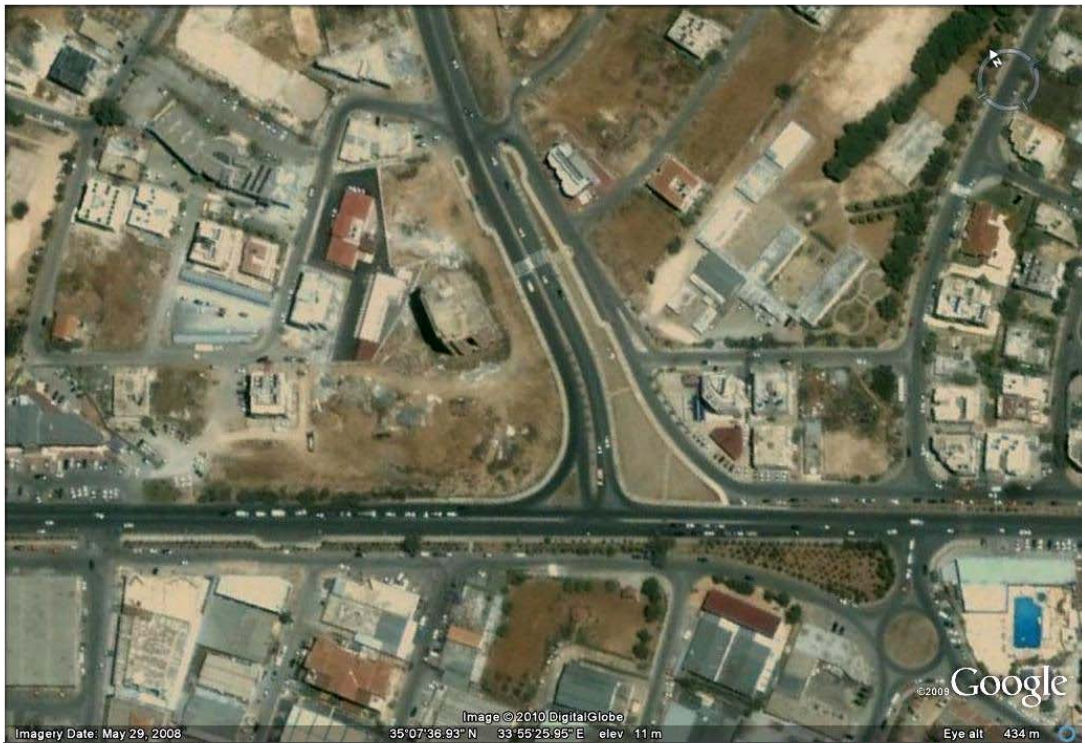


Figure 4.7 Real picture of traffic intersection in Famagusta city (from Google Earth)

4.2 Computer simulation results

In this section several scenarios with fuzzy variables of input parameters are considered. The computer simulation using Matlab software is carried out for two different cases: using four input parameters, and using three input parameters.

In all scenarios the time duration of green signal is 45 seconds and the prediction time is 10 seconds, i.e. the number of arriving vehicles is predicted for the next 10 seconds.

(Scenario 1). In the first scenario suppose the MLTQRS is a small number equal to 4. It means that the maximum number of vehicles behind red signal on other arms is 4. ARJGS is 0.13. It means that the rate of current arriving vehicles (number of arriving vehicles per seconds) is few. RTGS is also a small number 0.2, it means that 20% of green signal time (that totally lasts 45 sec.) remains. This time is $0.2 \times 45 = 9\ sec.$, i.e. in 9 seconds green phase should change to red phase. Suppose the PVC is a high number 9. It means that 9 vehicles will reach the intersection in 10 seconds. In this condition because the traffic of other arms is low and many vehicles arrive in short period of time (10 seconds), it is better to extend the green signal time to permit the mass of arriving vehicles to pass the intersection, otherwise in a very short time many vehicles will be behind the red signal. It means that the MLTQRS becomes "long" in a very short time and it forces other arms to reduce the green signal, and totally the rate of vehicles which will pass the intersection in determined time becomes very few. In other words, the total delay of vehicles becomes higher.

The figures 4.8 and 4.9 depict the results of computer simulation for the first scenario with four (including PVC) and three (excluding PVC) input parameters, respectively.

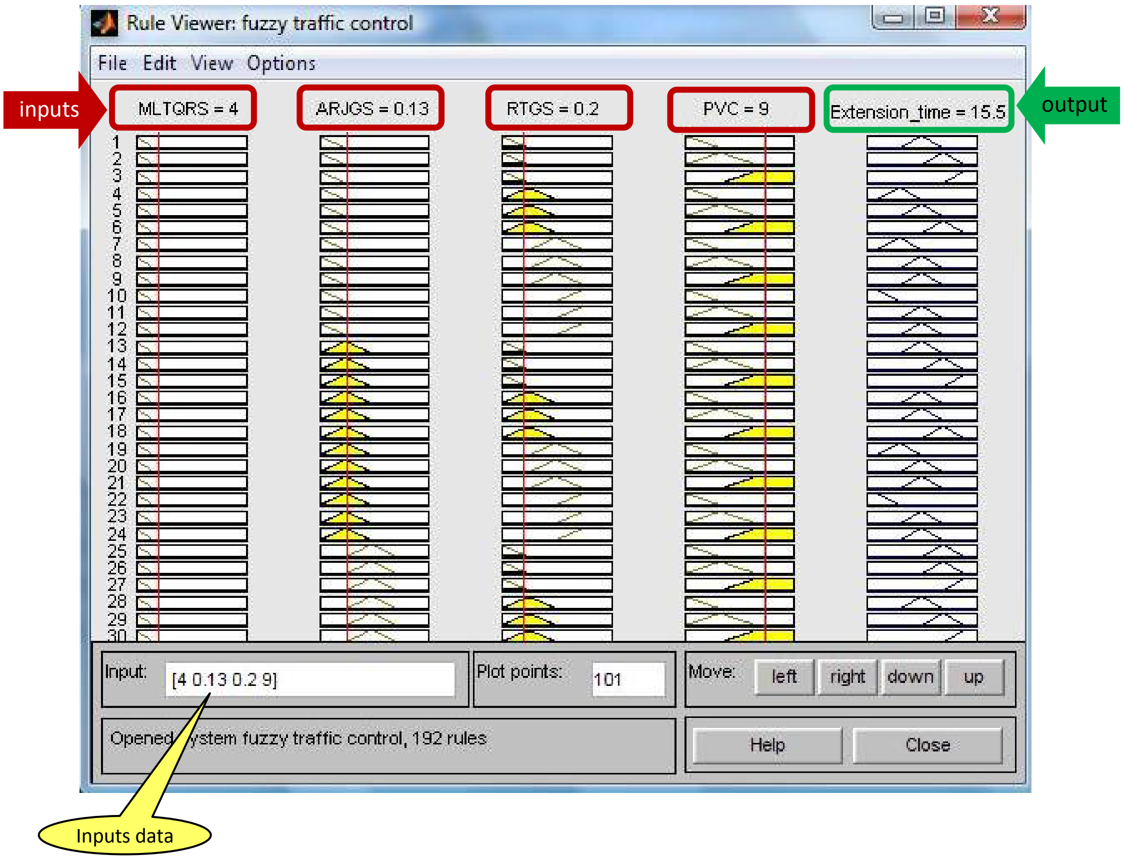


Figure 4.8 Result of extension time with considering PVC in first scenario

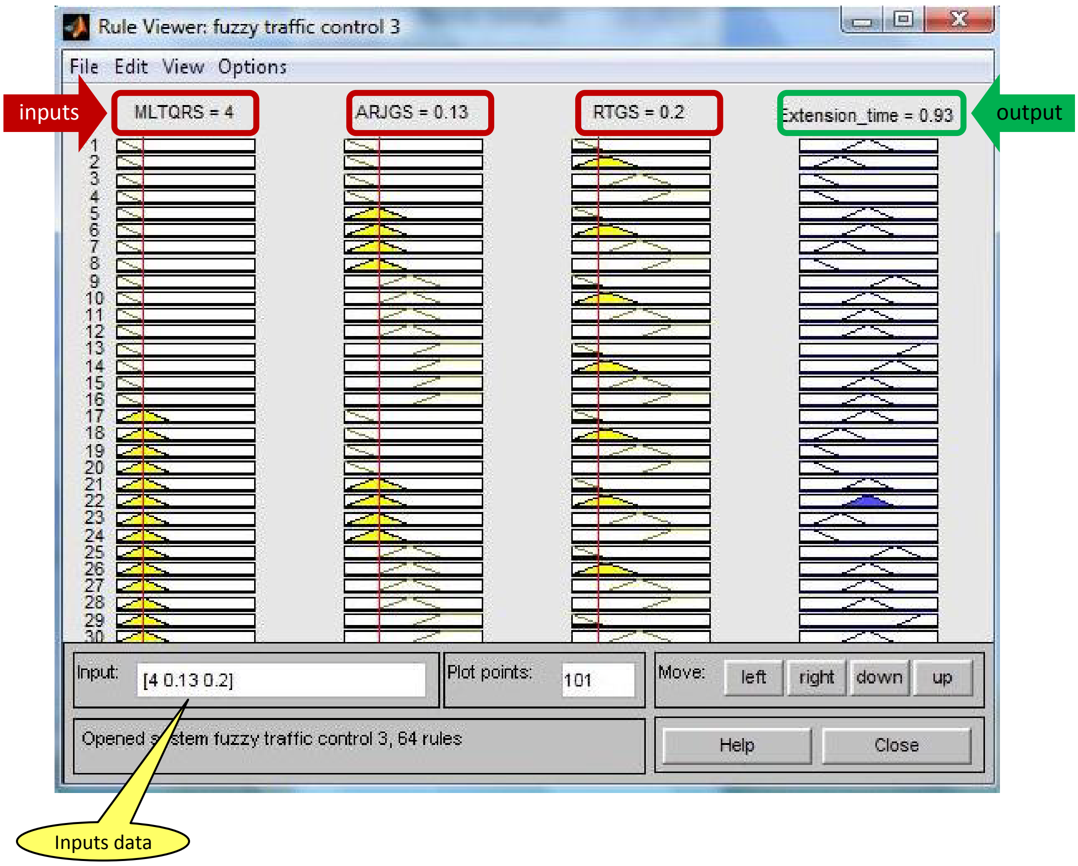


Figure 4.9 Result of extension time without considering PVC in first scenario

As we can see from the figure 4.8, the remaining time for the green signal is 9 seconds. Figure 4.8 shows the effectiveness of the control system regarding to PVC, the extension time increases for 15.5 seconds, and totally the remaining time becomes $9 + 15.5 \ = 24.5$ seconds. This time is enough for the mass of vehicles to pass the intersection.

In figure 4.9 the output value is 0.93. It means the control system increases time for 0.93 seconds and totally the remaining green signal time is $9 + 0.93 \ = 9.93$ seconds. In this condition in 9.93 seconds the green phase will change to red phase, and we know that PVC predicts that 9 vehicles will reach the intersection in 10 seconds. In fact all the 9 vehicles (group of vehicles) should stay behind the red light in a very short time. This fact affects other arms to decrease their green signal time even if the ARJGS is “moderate” on those arms.

(Scenario 2). In the second scenario the MLTQRS is 4, the ARJGS is 0.13, and the RTGS is 0.8. PVC is again 9, and the queue of other arms is rather short. The arrival rate is rather low, but the remaining time of green signal is 0.8, or in other words, $0.8 \times 45 = 36$ seconds remain to the end of the green signal, and we know that there is a congestion of vehicles (9 vehicles) that will reach the intersection in 10 seconds. The figures 4.10 and 4.11 depict the results of computer simulation for the second scenario with four (including PVC) and three (excluding PVC) input parameters, respectively.

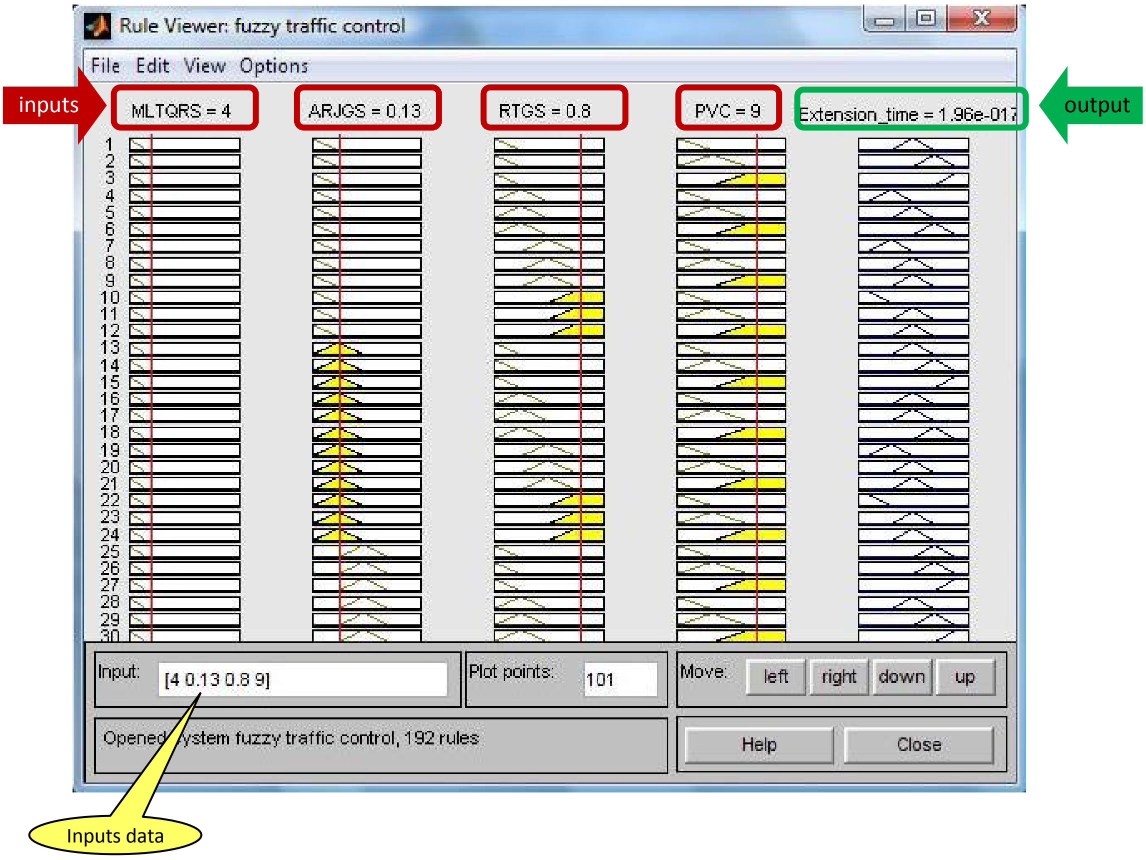


Figure 4.10 Result of extension time with considering PVC in second scenario

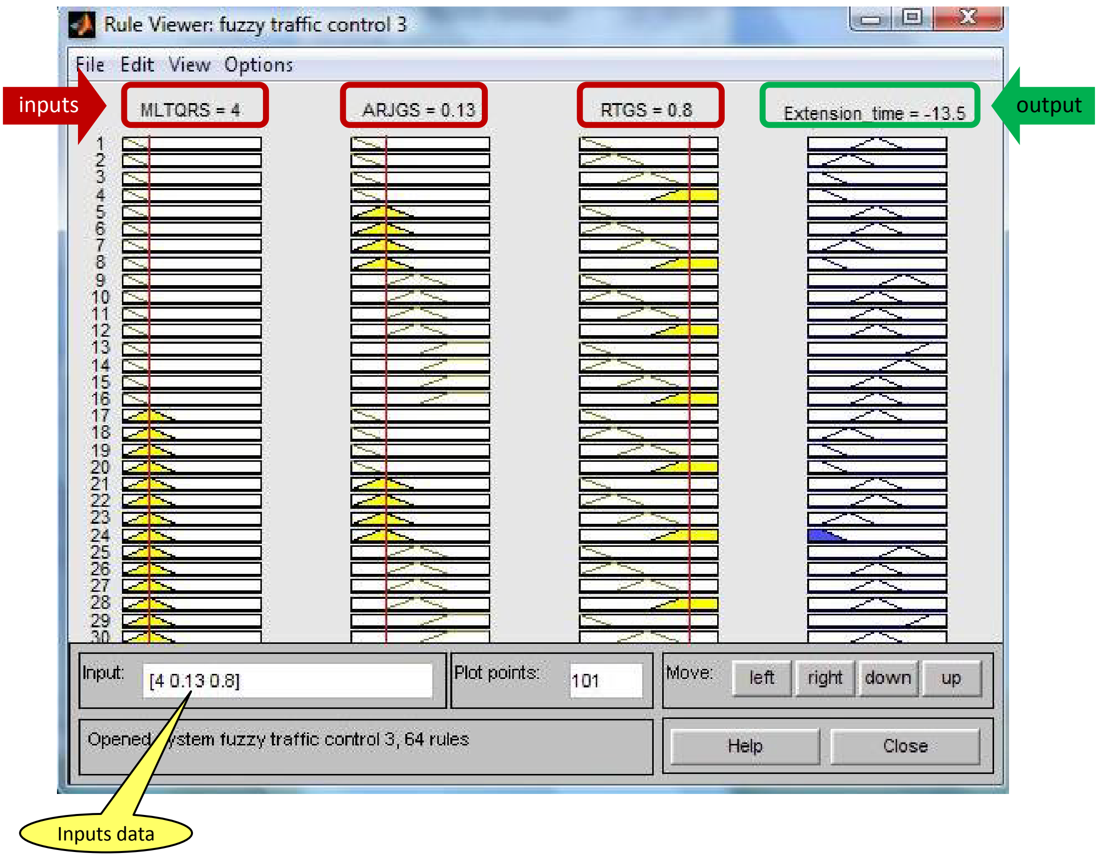


Figure 4.11 Result of extension time without considering PVC in second scenario

From the result in figure 4.10 we can see that the extension time is 1.96e-017 with considering PVC. This is a very small number, so totally the remaining green signal time does not change. The reason is that the control system maintains the remaining time for the mass of vehicles to cross the intersection.

Figure 4.11 shows that the output value without considering PVC is -13.5. The remaining green signal decreases to $36 - 13.5 = 22.5$ seconds. We know that in 10 seconds 9 vehicles will arrive, but obviously 12.5 (22.5 – 10 = 12.5) seconds are not enough for the road with one lane where 9 vehicles want to cross the intersection. Therefore fuzzy traffic control system with PVC makes a better decision than the system without PVC.

(Scenario 3). In the third scenario suppose the MLTQRS is again a big number 9. ARJGS is high with 0.35, it means every second 0.35 vehicles arrive to the intersection. The RTGS is also a big number 0.8, it means 80% of green signal time remain, or $0.8 \times 45 = 36$ seconds remains until the green signal ends and the PVC is very few equal to 2.

The figures 4.12 and 4.13 depict the results of computer simulation for the third scenario with four (including PVC) and three (excluding PVC) input parameters, respectively.

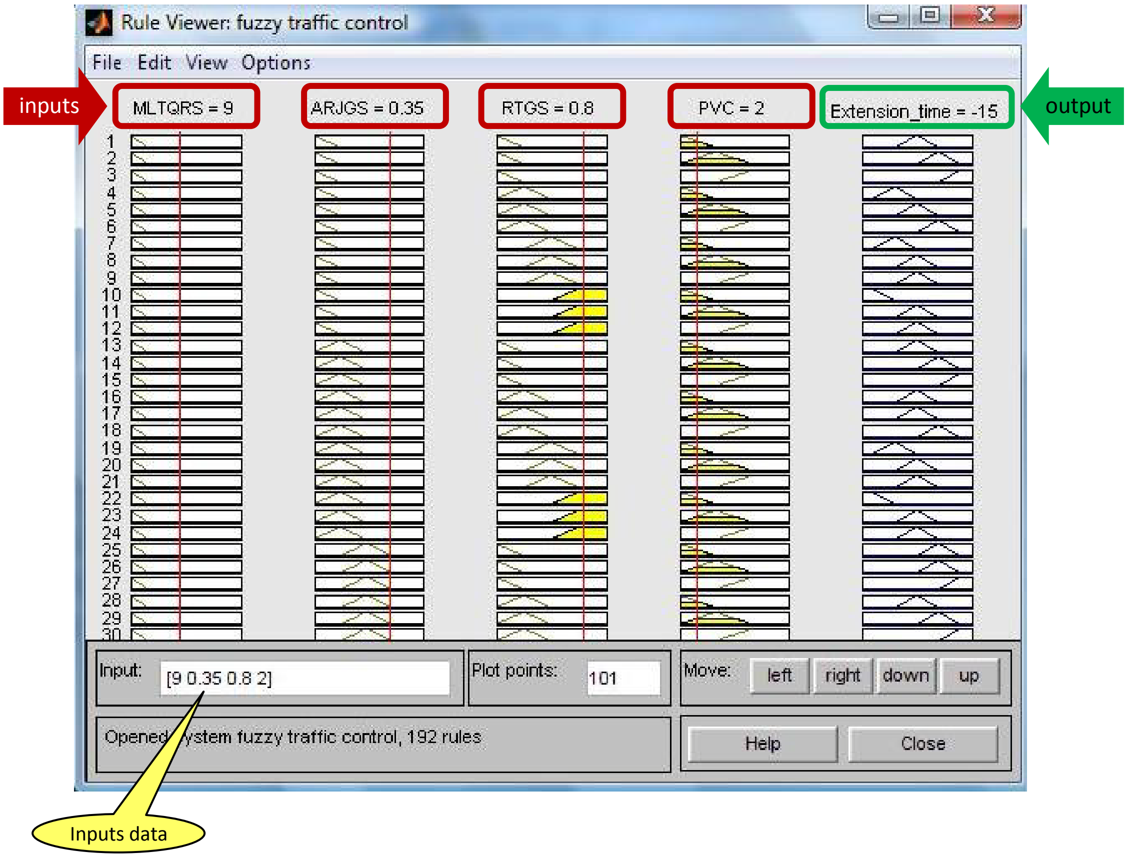


Figure 4.12 Result of extension time with considering PVC in third scenario

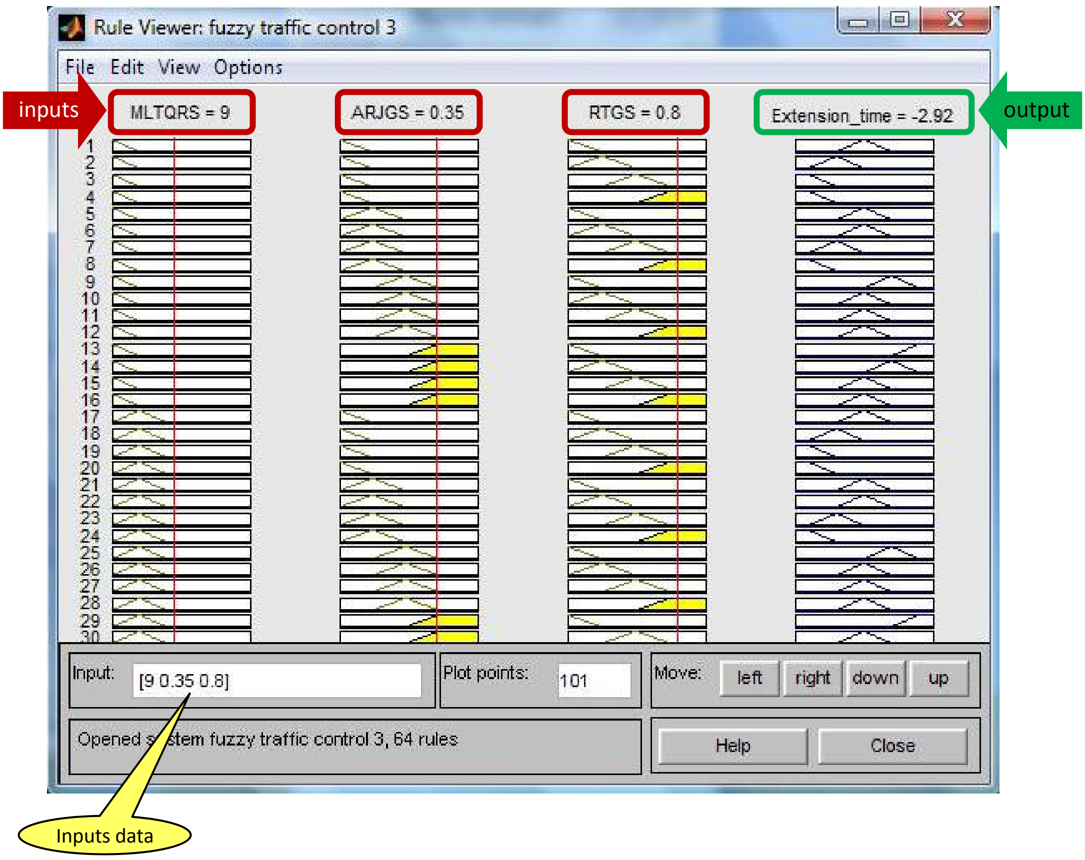


Figure 4.13 Result of extension time without considering PVC in third scenario

Figure 4.12 shows that the time decreases for 15 seconds. In this case the RTGS is 0.8 (it is 0.8*45 = 36 seconds). After the decision of the control system the time decreases for 15 seconds and the remaining time of green signal becomes $36 - 15 = 21$ seconds. In this scenario the MLTQRS is a big number, ARJGS is high, and the PVC is a small number, or in other words, many vehicles are waiting for green signal on other arms and also many vehicles currently are crossing intersection, but we know that in 10 seconds there will be a few number of vehicles. The best decision is to permit these many arriving vehicles to cross the intersection, and also immediately end the green signal to permit vehicles on other arms to cross the intersection.

Figure 4.13 shows the simulation result of third scenario without PVC. The time is -2.92. The control system decreases the green signal time to $36 - 2.92 = 33.08$ seconds. So the extension time does not change, but a better decision is “more decrease” (green phase duration), so vehicles on other arms will be able to cross the intersection.

(Scenario 4). In the fourth scenario the MLTQRS and ARJGS are again same as in previous scenario, and they are 9 and 0.35, respectively, but the RTGS is 0.2. The difference in this scenario is the remaining time which it is about $0.2 \times 45 = 9$ seconds. The figures 4.14 and 4.15 depict the results of computer simulation for the fourth scenario with four (including PVC) and three (excluding PVC) input parameters, respectively.

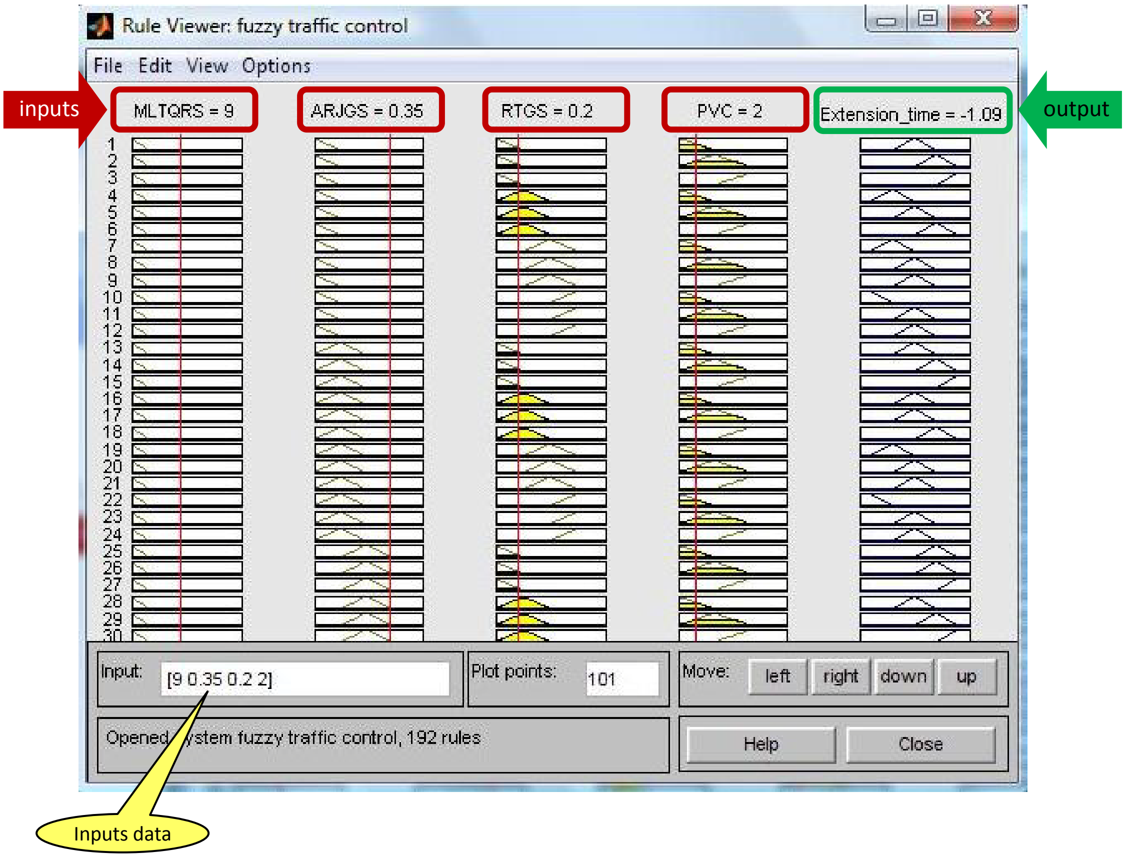


Figure 4.14 Result of extension time with considering PVC in fourth scenario

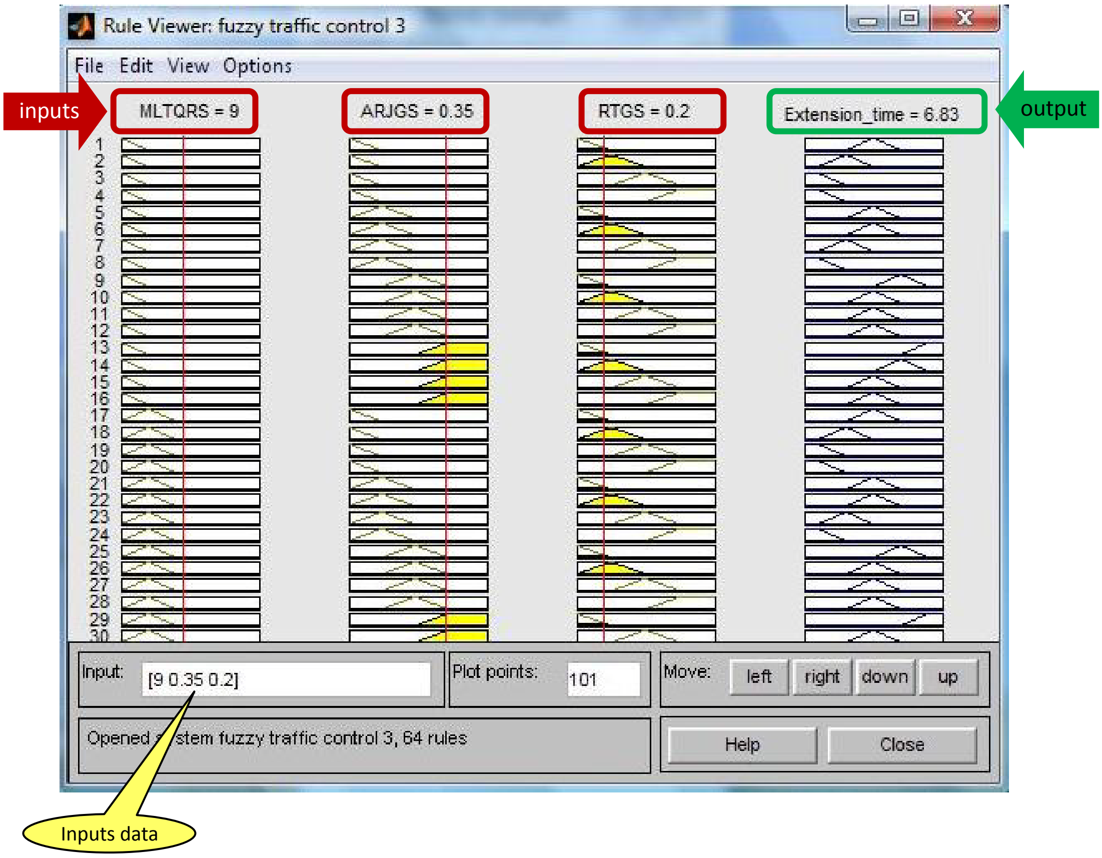


Figure 4.15 Result of extension time without considering PVC in fourth scenario

Figure 4.14 shows that the extension time is -1.09, or the remaining green time is $9 - 1.09 = 7.91$ seconds. The control system decides not to change the extension time very much. We know that the arrival rate is high, but in 10 seconds the congestion is very low and 7.91 seconds are enough time to permit arriving vehicles with high rate to cross the intersection.

In the simulation result for the fourth scenario without considering PVC the extension time is 6.83 seconds, or totally the remaining time is $9 + 6.83 = 15.83$, but we know that in 10 seconds the vehicle congestion will be very low. Extending the green signal time in this case when the remaining time is 9 seconds is a wrong decision. The fuzzy traffic controller with PVC again makes a better decision than the fuzzy traffic controller without PVC.

(Scenario 5). In the fifth scenario the MLTQRS is 8, the ARJGS is 0.05, RTS is 0.3, and PVC is 10. It means the queue of vehicles on other arms is approximately medium, the arrival rate of vehicles is very low, the remaining time of green signal is $0.3 \times 45 = 13.5$ seconds, and the PVC shows that many vehicles reach the intersection in 10 seconds.

The figures 4.16 and 4.17 depict the results of computer simulation for the fifth scenario with four (including PVC) and three (excluding PVC) input parameters, respectively.

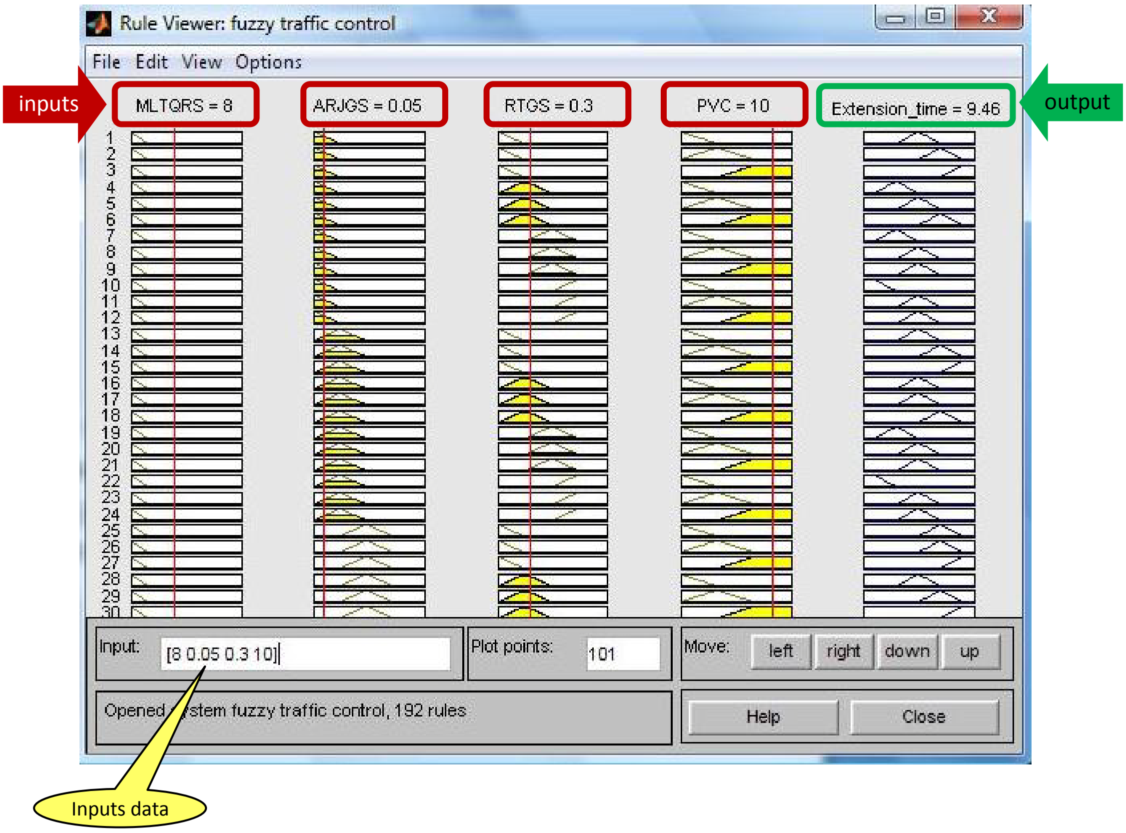


Figure 4.16 Result of extension time with considering PVC in fifth scenario

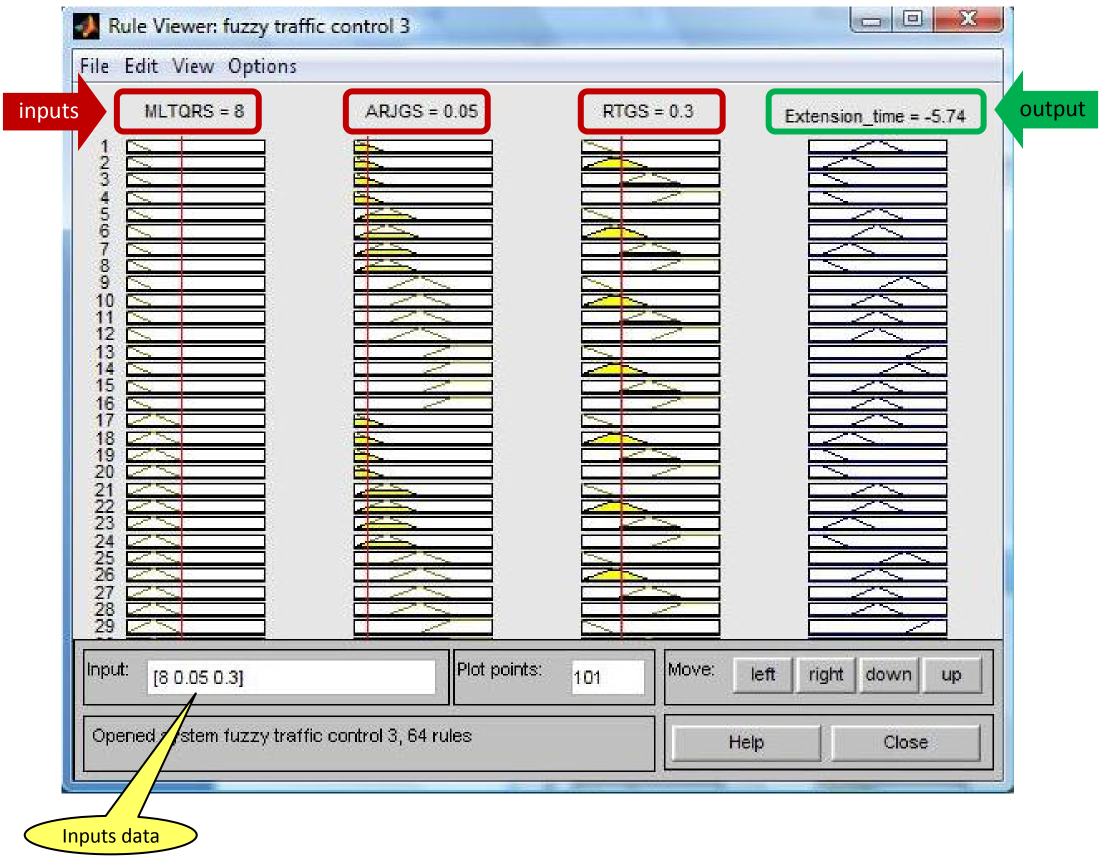


Figure 4.17 Result of extension time without considering PVC in fifth scenario

Figure 4.16 shows that the time increases for 9.46 seconds, or totally the remaining time of green signal is $13.5 + 9.46 = 22.96$ seconds. This time is enough for the group of vehicles to cross the intersection.

Figure 4.17 shows that the remaining green time decreases for -5.74, or totally the remaining green signal time is $13.5 - 5.74 = 7.76$ seconds. This is not a good decision, because we know that a group of vehicles will reach the intersection in 10 seconds, but in 7.76 seconds the green light will change to red light and the control system will cause many vehicles to stop behind the red light in a very short time.

(Scenario 6). In the sixth scenario the MLTQRS is 7, it means the queue has rather medium length. ARJGS is 0.22, and it is related to the “moderate” linguistic term. RTGS is 0.4, or $0.4 \times 45 = 18$ seconds remain until the green signal ends. The PVC is 5, i.e. there are 5 vehicles which will arrive at the intersection in 10 seconds, and it is not a high number. The control system decides to increase the remaining green signal time for 1.26 seconds, or in $18 + 1.26 = 19.26$ seconds the green signal ends. The figures 4.18 and 4.19 depict the results of sixth scenario with four (including PVC) and three (excluding PVC) input parameters, respectively.

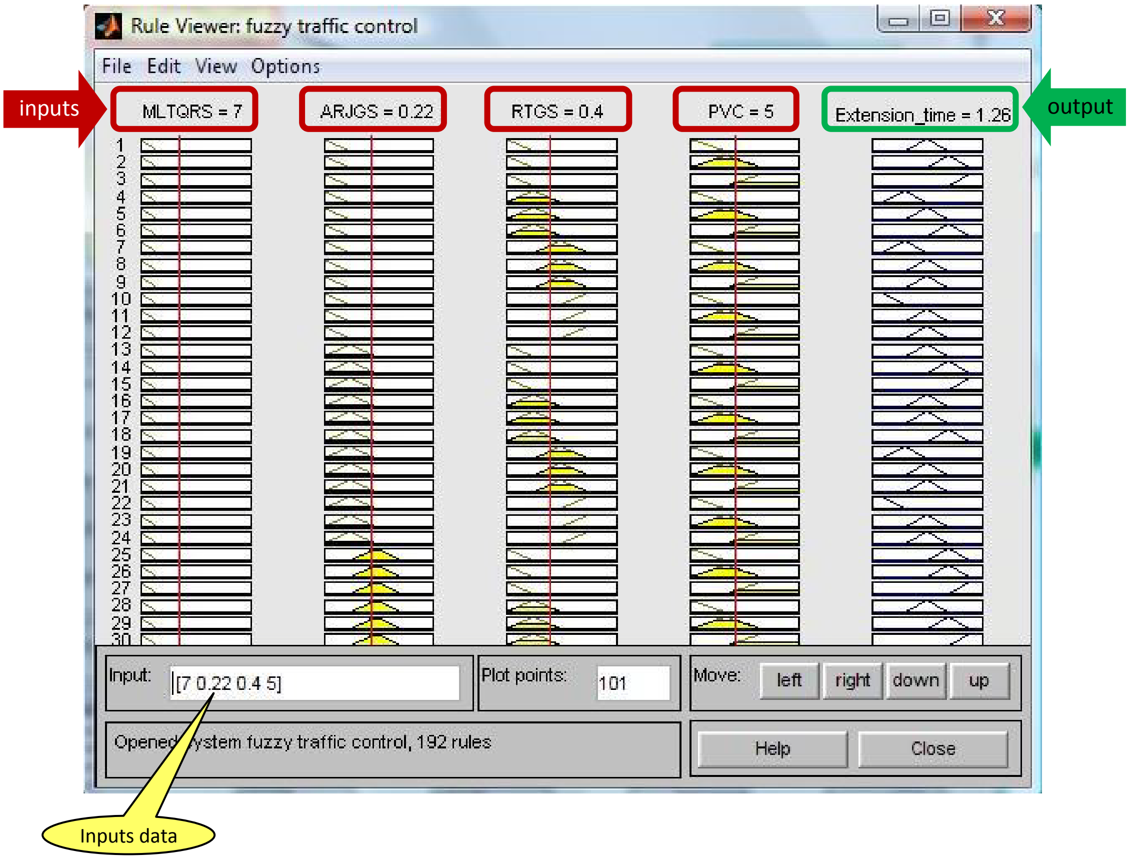


Figure 4.18 Result of extension time with considering PVC in sixth scenario

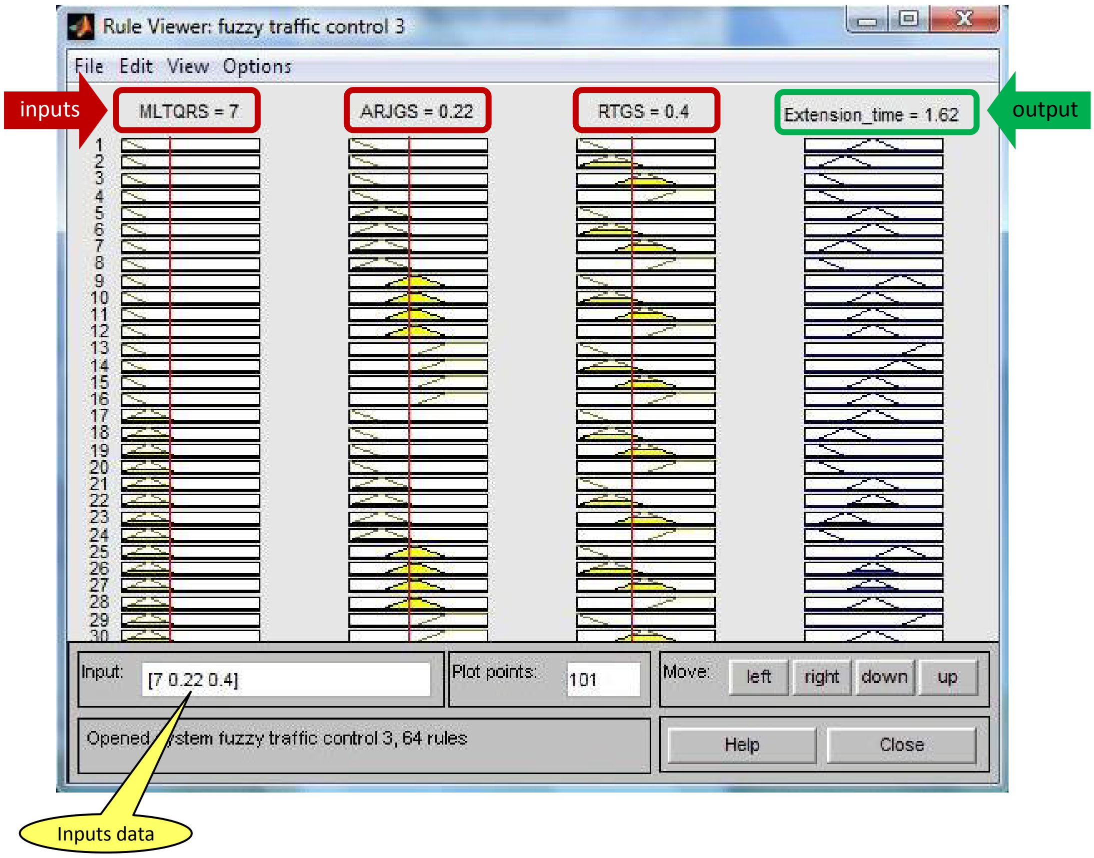


Figure 4.19 Result of extension time without considering PVC in sixth scenario

Figure 4.19 shows that the simulation result for the control system without considering PVC is very similar to the control system with considering PVC. In the case without considering PVC the output is equal to 1.62, but control system with considering PVC is 1.26 (Figure 4.18). It means that in this case the extra input (PVC) cannot significantly change the result. For this case ARJGS is 0.22, and it means that the arrival rate of vehicles is approximately moderate and the PVC is 5, so the congestion of vehicles in 10 seconds is approximately moderate. The conclusion is that this arrival rate of vehicles is the same in 10 seconds.

(Scenario 7). In the seventh scenario the MLTQRS is 2, the ARJGS is 0.4, the RTGS is 0.75, and the PVC is 8. MLTQRS shows that the queues of other arms are maximum 2 (very short queue), and the arrival rate of vehicles is high, the remaining time of green signal is $0.75 \times 45 = 33.75$ seconds, and the PVC shows that many vehicles will reach in 10 seconds.

The figures 4.20 and 4.21 depict the results of the seventh scenario with four (including PVC) and three (excluding PVC) input parameters, respectively.

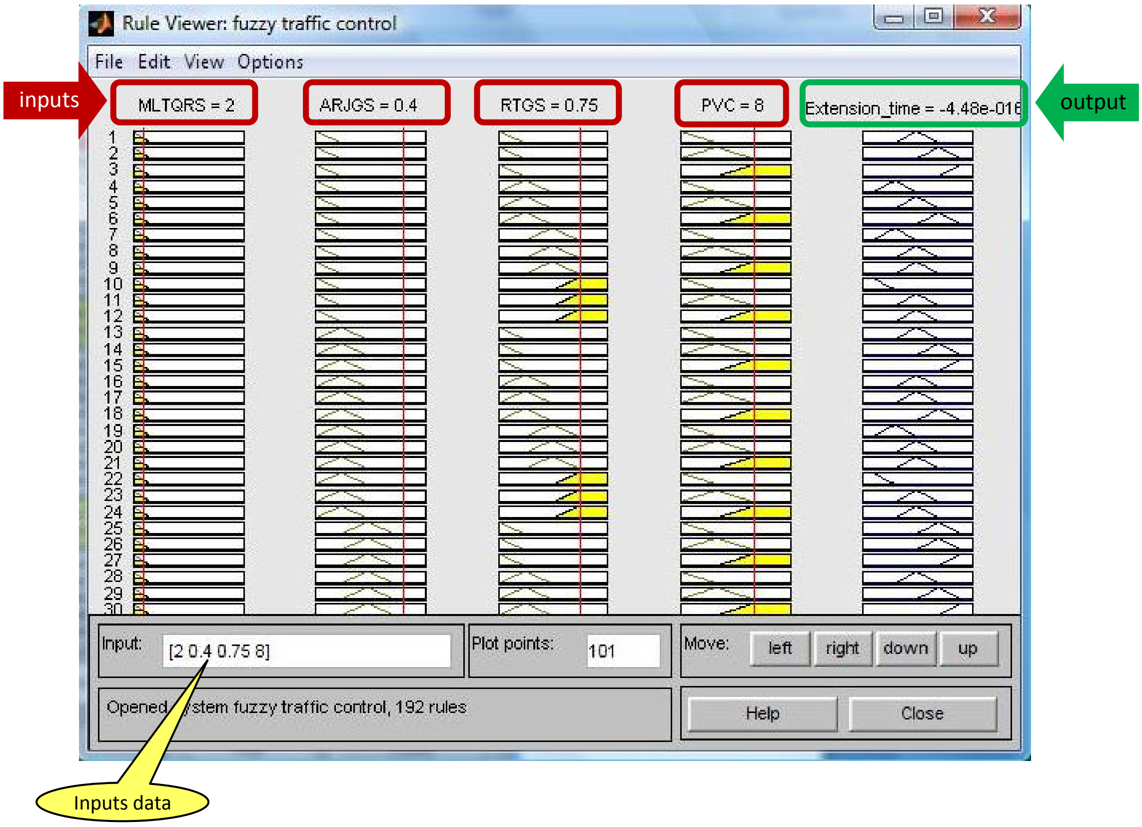


Figure 4.20 Result of extension time with considering PVC in seventh scenario

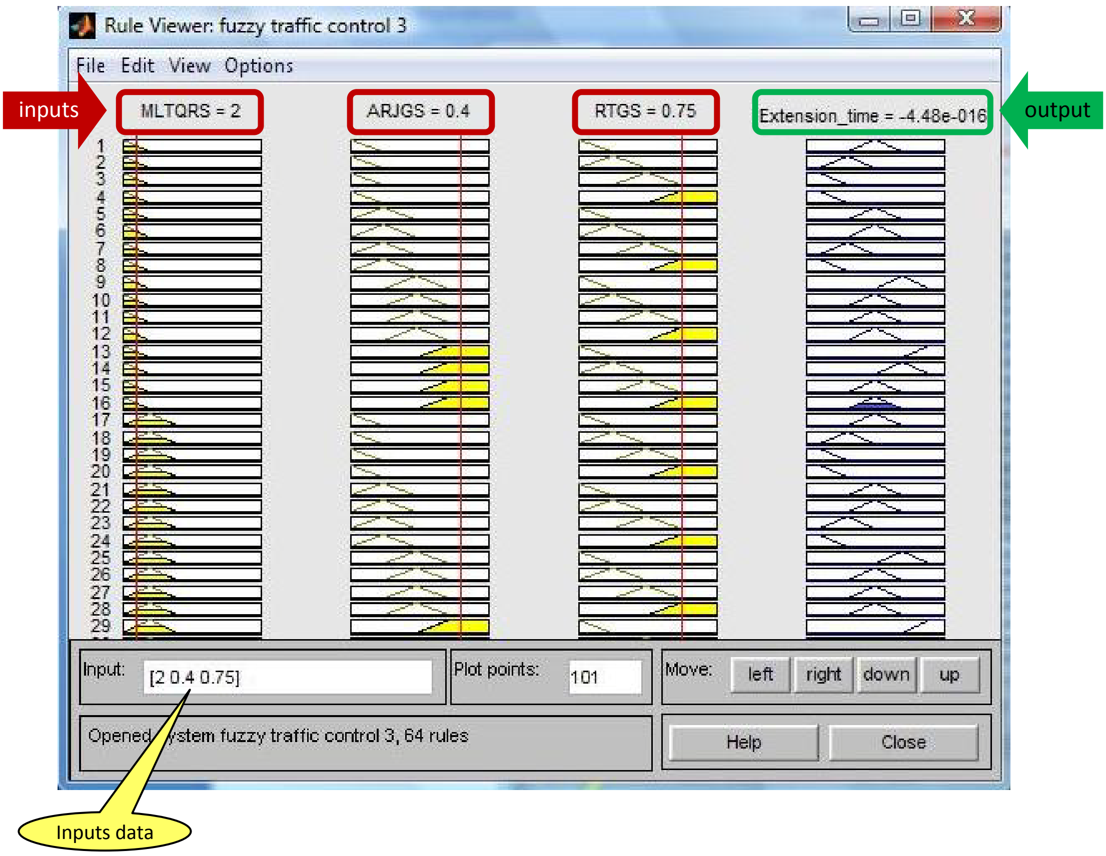


Figure 4.21 Result of extension time without considering PVC in seventh scenario

Figure 4.21 shows the result of control system without considering PVC, and the extension time is a very small number and totally the remaining green signal time does not change.

In the seventh scenario the extension time without considering PVC is the same as extension time with considering PVC, and it is equal to -4.48e-16.

From sixth and seventh scenarios we can conclude that when the values of ARJGS and PVC are close, the outputs of fuzzy traffic control system with PVC and without PVC become similar.

According to the different traffic situations, the fuzzy traffic controller can adjust the extension time of green phase of traffic lights. Because of this factor, it is obvious that the fuzzy traffic controller shows significantly better performance comparing to fixed time controller.

We can also see that using extra fourth input in the controller is very effective when the linguistic terms of ARJGS are inverse of linguistic terms of PVC, and the fuzzy traffic control system shows almost similar performance when the values of ARJGS and PVC are represented by the same linguistic terms. Actually both ARJGS and PVC determine the congestion of vehicles in different conditions. When ARJGS and PVC are represented by different linguistic variables, the condition of congestion of vehicles will be different in 10 seconds. Therefore the decision of control system with four input parameters becomes more accurate comparing to control system with three input parameters.

In the table 4.3 we present all the possible rules (scenarios) for the fuzzy logic controller with four input parameters and one output parameter. As we know, three of input parameters are represented by four linguistic terms and one input is represented by three linguistic terms. So there are totally 192 ($4 \times 4 \times 4 \times 3 = 192$) rules (The range of each linguistic term is given in section 3.1. The logical inference is done using Mamdani inference engine in Matlab software).

Table 4.3 Rules for the fuzzy logic controller with four inputs and one output parameters

#	MLTQRS	ARJGS	RTGS	PVC	Extension time
1	very small	very few	very few	few	do not change
2	very small	very few	very few	moderate	increase
3	very small	very few	very few	many	more increase
4	very small	very few	few	few	decrease
5	very small	very few	few	moderate	do not change
6	very small	very few	few	many	increase
7	very small	very few	medium	few	decrease
8	very small	very few	medium	moderate	do not change
9	very small	very few	medium	many	do not change
10	very small	very few	long	few	more decrease
11	very small	very few	long	moderate	do not change
12	very small	very few	long	many	do not change
13	very small	few	very few	few	do not change
14	very small	few	very few	moderate	increase
15	very small	few	very few	many	more increase
16	very small	few	few	few	do not change
17	very small	few	few	moderate	do not change
18	very small	few	few	many	increase
19	very small	few	medium	few	decrease
20	very small	few	medium	moderate	do not change
21	very small	few	medium	many	do not change
22	very small	few	long	few	more decrease
23	very small	few	long	moderate	do not change
24	very small	few	long	many	do not change
25	very small	moderate	very few	few	increase
26	very small	moderate	very few	moderate	increase

27	very small	moderate	very few	many	more increase
28	very small	moderate	few	few	do not change
29	very small	moderate	few	moderate	increase
30	very small	moderate	few	many	more increase
31	very small	moderate	medium	few	do not change
32	very small	moderate	medium	moderate	do not change
33	very small	moderate	medium	many	increase
34	very small	moderate	long	few	more decrease
35	very small	moderate	long	moderate	do not change
36	very small	moderate	long	many	do not change
37	very small	many	very few	few	more increase
38	very small	many	very few	moderate	more increase
39	very small	many	very few	many	more increase
40	very small	many	few	few	increase
41	very small	many	few	moderate	more increase
42	very small	many	few	many	more increase
43	very small	many	medium	few	do not change
44	very small	many	medium	moderate	do not change
45	very small	many	medium	many	increase
46	very small	many	long	few	decrease
47	very small	many	long	moderate	do not change
48	very small	many	long	many	do not change
49	small	very few	very few	few	do not change
50	small	very few	very few	moderate	increase
51	small	very few	very few	many	more increase
52	small	very few	few	few	do not change
53	small	very few	few	moderate	increase
54	small	very few	few	many	more increase
55	small	very few	medium	few	decrease
56	small	very few	medium	moderate	do not change
57	small	very few	medium	many	increase
58	small	very few	long	few	more decrease
59	small	very few	long	moderate	do not change
60	small	very few	long	many	do not change
61	small	few	very few	few	do not change
62	small	few	very few	moderate	more increase
63	small	few	very few	many	more increase
64	small	few	few	few	do not change
65	small	few	few	moderate	increase

66	small	few	few	many	more increase
67	small	few	medium	few	decrease
68	small	few	medium	moderate	do not change
69	small	few	medium	many	increase
70	small	few	long	few	more decrease
71	small	few	long	moderate	do not change
72	small	few	long	many	do not change
73	small	moderate	very few	few	increase
74	small	moderate	very few	moderate	more increase
75	small	moderate	very few	many	more increase
76	small	moderate	few	few	do not change
77	small	moderate	few	moderate	increase
78	small	moderate	few	many	more increase
79	small	moderate	medium	few	do not change
80	small	moderate	medium	moderate	do not change
81	small	moderate	medium	many	increase
82	small	moderate	long	few	decrease
83	small	moderate	long	moderate	do not change
84	small	moderate	long	many	do not change
85	small	many	very few	few	more increase
86	small	many	very few	moderate	more increase
87	small	many	very few	many	more increase
88	small	many	few	few	increase
89	small	many	few	moderate	more increase
90	small	many	few	many	more increase
91	small	many	medium	few	decrease
92	small	many	medium	moderate	do not change
93	small	many	medium	many	increase
94	small	many	long	few	decrease
95	small	many	long	moderate	do not change
96	small	many	long	many	do not change
97	medium	very few	very few	few	decrease
98	medium	very few	very few	moderate	decrease
99	medium	very few	very few	many	decrease
100	medium	very few	few	few	more decrease
101	medium	very few	few	moderate	more decrease
102	medium	very few	few	many	more increase
103	medium	very few	medium	few	more decrease
104	medium	very few	medium	moderate	do not change

105	medium	very few	medium	many	do not change
106	medium	very few	long	few	more decrease
107	medium	very few	long	moderate	more decrease
108	medium	very few	long	many	do not change
109	medium	few	very few	few	do not change
110	medium	few	very few	moderate	do not change
111	medium	few	very few	many	more increase
112	medium	few	few	few	more decrease
113	medium	few	few	moderate	more decrease
114	medium	few	few	many	increase
115	medium	few	medium	few	more decrease
116	medium	few	medium	moderate	decrease
117	medium	few	medium	many	do not change
118	medium	few	long	few	more decrease
119	medium	few	long	moderate	more decrease
120	medium	few	long	many	do not change
121	medium	moderate	very few	few	increase
122	medium	moderate	very few	moderate	increase
123	medium	moderate	very few	many	more increase
124	medium	moderate	few	few	do not change
125	medium	moderate	few	moderate	do not change
126	medium	moderate	few	many	increase
127	medium	moderate	medium	few	decrease
128	medium	moderate	medium	moderate	do not change
129	medium	moderate	medium	many	do not change
130	medium	moderate	long	few	more decrease
131	medium	moderate	long	moderate	more decrease
132	medium	moderate	long	many	do not change
133	medium	many	very few	few	increase
134	medium	many	very few	moderate	increase
135	medium	many	very few	many	more increase
136	medium	many	few	few	do not change
137	medium	many	few	moderate	do not change
138	medium	many	few	many	increase
139	medium	many	medium	few	decrease
140	medium	many	medium	moderate	decrease
141	medium	many	medium	many	do not change
142	medium	many	long	few	more decrease
143	medium	many	long	moderate	more decrease

144	medium	many	long	many	do not change
145	long	very few	very few	few	do not change
146	long	very few	very few	moderate	do not change
147	long	very few	very few	many	do not change
148	long	very few	few	few	more decrease
149	long	very few	few	moderate	more decrease
150	long	very few	few	many	more decrease
151	long	very few	medium	few	more decrease
152	long	very few	medium	moderate	decrease
153	long	very few	medium	many	do not change
154	long	very few	long	few	more decrease
155	long	very few	long	moderate	more decrease
156	long	very few	long	many	decrease
157	long	few	very few	few	do not change
158	long	few	very few	moderate	do not change
159	long	few	very few	many	do not change
160	long	few	few	few	more decrease
161	long	few	few	moderate	more decrease
162	long	few	few	many	do not change
163	long	few	medium	few	more decrease
164	long	few	medium	moderate	more decrease
165	long	few	medium	many	decrease
166	long	few	long	few	more decrease
167	long	few	long	moderate	more decrease
168	long	few	long	many	decrease
169	long	moderate	very few	few	do not change
170	long	moderate	very few	moderate	do not change
171	long	moderate	very few	many	do not change
172	long	moderate	few	few	more decrease
173	long	moderate	few	moderate	more decrease
174	long	moderate	few	many	do not change
175	long	moderate	medium	few	more decrease
176	long	moderate	medium	moderate	more decrease
177	long	moderate	medium	many	do not change
178	long	moderate	long	few	more decrease
179	long	moderate	long	moderate	more decrease
180	long	moderate	long	many	decrease
181	long	many	very few	few	increase
182	long	many	very few	moderate	increase

183	long	many	very few	many	more increase
184	long	many	few	few	decrease
185	long	many	few	moderate	do not change
186	long	many	few	many	do not change
187	long	many	medium	few	more decrease
188	long	many	medium	moderate	more decrease
189	long	many	medium	many	decrease
190	long	many	long	few	more decrease
191	long	many	long	moderate	more decrease
192	long	many	long	many	decrease

Chapter 5

CONCLUSION

In this thesis the fuzzy intelligent traffic control system is presented that optimally manages the traffic flow would be acheived at the intersections.

The computer simulation results show that the performance of the fuzzy traffic controller with four input parameters is better than with three input parameters, i.e. the fourth input parameter can significantly increase the accuracy of the fuzzy traffic controller. In complex intersections the performance of the proposed fuzzy controller is better than the performance of conventional fixed time controller.

The advantage of fuzzy traffic controller consists in minimization of delay of vehicles that reach the safe traffic volume at the intersections.

The extension time of the green phase of the traffic lights is adjusted using Mamdani inference.

REFERENCES

[1] http://en.wikipedia.org/wiki/Fuzzy_system

[2] J. Niittymaki, T. Kosonen, and R. Nevala. (2001). Fuzzy traffic signal control in major arterials. *2001 IEEE Intelligent Transportation Systems Conference Proceedings*, Oakland (CA) USA, 346-351.

[3] Xu Liqun and Jiang Fu. (2002). Fuzzy control of traffic congestion diversion in the presence of information. *TENCON '02. Proceedings. 2002 IEEE Region 10 Conference on Computers, Communications, Control and Power Engineering, vol. 3,* 1737-1740.

[4] A. Akramizadeh, A. Afshar, Mohammad-R., and Akbarzadeh-T. (2006). Decentralized Temporal Fuzzy Discrete Event Control in Urban Traffic Management. *IEEE International Conference on Industrial Technology (ICIT'06),* 2663-2668.

[5] Jan-Dirk Schmöcker, Sonal Ahuja, and Michael G.H. Bell. (2008). Multi-objective signal control of urban junctions – Framework and a London case study. *Transportation Research Part C: Emerging Technologies, vol. 16, no. 4,* 454-470.

[6] Y. Sazi Murat and Ergun Gedizlioglu.(2005). A fuzzy logic multi-phased signal control model for isolated junctions. *Transportation Research Part C: Emerging Technologies, vol. 13, no. 1*, 19-36.

[7] Fengxiang Qiao, Ping Yi, Hai Yang, and S. Devarakonda. (2002). Fuzzy logic based intersection delay estimation. *Mathematical and Computer Modeling, vol. 36, no. 11-13*, 1425-1434.

[8] Chih-Hsun Chou and Jen-Chao Teng. (2002). A fuzzy logic controller for traffic junction signals. *Information Sciences, vol. 143, no. 1-4,* 73-97.

[9] Marjan Kaedi, Naser Movahhedinia, and Kamal Jamshidi. (2008). Traffic signal timing using two-dimensional correlation, neuro-fuzzy and queuing based neural. *Neural Computing & Applications, vol. 17, no. 2*, 193-200.

[10] Shanshan Zhang and Guanrong Chen. (2006). A New Model-Free Fuzzy Logic Controller for Truck-Parking. *Sixth International Conference on Intelligent Systems Design and Applications*, *ISDA '06, vol. 2*, 49-54.

[11] Joon-Yong Lee and Ju-Jang Lee.(2007). Multiple Designs of Fuzzy Controllers for Car Parking Using Evolutionary Algorithm. *4th IEEE International Conference on Mechatronics, ICM2007*, 1-6.

[12] Dušan Teodorović and Panta Lučić. (2006). Intelligent parking systems. *European Journal of Operational Research, vol. 175, no. 3,* 1666-1681.

[13] J. Alejandro Lopez, R. Garcia, A. Garcia Blanco, and I.A. Zuniga Felix. (2007). Traffic Lights Fuzzy Control Proposals to Improve Vehicular Flow. *Electronics, Robotics and Automotive Mechanics Conference, 2007, CERMA 2007*, 406-411.

[14] Moein Shakeri, Hossein Deldari, Alireza Rezvanian, and Homa Foroughi.(2008).A novel fuzzy method to traffic light control based on unidirectional selective cellular automata for urban. *11th International Conference on Computer and Information Technology, ICCIT 2008*, 300-305.

[15] GiYoung Lim, JeongJin Kang, and YouSik Hong. (2001). The optimization of traffic signal light using artificial intelligence. *The 10th IEEE International Conference on Fuzzy Systems, vol. 3*, 1279-1282.

[16] Y. Chong, C. Quek, and P. Loh.(2009). A novel neuro-cognitive approach to modeling traffic control and flow based on fuzzy neural techniques. *Expert Systems with Applications, Volume 36, Issue 3, Part 1*, 4788-4803.

[17] Hongbin Yin, S. C. Wong, Jianmin Xu, and C. K. Wong. (2002). Urban traffic flow prediction using a fuzzy-neural approach. *Transportation Research Part C: Emerging Technologies, vol. 10, no. 2*, 85-98.

[18] Ella Bingham. (2001). Reinforcement learning in neurofuzzy traffic signal control. *European Journal of Operational Research, vol. 131, no. 2,* 232-241.

[19] Alexander Paz and Srinivas Peeta. (2009). Information-based network control strategies consistent with estimated driver behavior. *Transportation Research Part B: Methodological, vol. 43, no. 1,* 73-96.

[20] Yaser E. Hawas. (2007). A fuzzy-based system for incident detection in urban street networks. *Transportation Research Part C: Emerging Technologies, vol. 15, no. 2*, 69-95.

[21] G. D. Lee and S. W. Kim. (2002). A longitudinal control system for a platoon of vehicles using a fuzzy-sliding mode algorithm. *Mechatronics, vol. 12, no. 1*, 97-118.

[22] J. Favilla, Machion, A. and Gomide, F. (1993). (1993). Fuzzy Traffic Control: Adaptive Strategies. *Second IEEE International Conference on on Fuzzy Systems,* San Francisco, CA, 506-511.

[23] Kevin M. Passino, Stephen Yurkovich. (1998). *Fuzzy Control.* Addison-Wesley.

[24] R.A.Aliev, R.R.Aliev. (2001). Soft Computing and its Applications. *World Scientific*.

[25] S. N. Sivanandam, S. Sumathi and S. N. Deepa. (2007). Introduction to Fuzzy Logic using MATLAB. *Springer*.

[26] Yigang Shi, P.C.Sen. (2000). A New Defuzzification Method for Fuzzy Control of Power Converters. *IEEE Industry Applications Conference*, 1202 – 1209.