Intelligent Traffic Control System for Over-Saturated Signalized Intersections in Kuwait

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***Abstract* -** This paper proposes a new intelligent traffic control (ITC) system which is more efficient than the traffic control system currently used in the state of Kuwait. The proposed ITC system is designed as a dynamic system by using a fuzzy expert system; the fuzzy rules are applied in the visual basic and computer-based program (Excel) to run the validation process. The developed control system applied on five intersections in the grid network at four periods. The results show that the number of vehicles passing the intersection phases is increased in most phases by an average of 12.9% at the first period, 23.3% at the second period, 10.4% at the third period and by 21.2% at the fourth period. For the same periods, the phases green time is increased by an average of 9.1%, 5.8%, 9.9% and 6.3%. And the number of intersection cycles remains constant at the most time which means that the developed control system distributes the phases green time dynamically based on the traffic situation.

Keywords - *Artificial Intelligence, Fuzzy Logic, Intelligent Transportation Systems, Neural Networks, Traffic Control Systems.*

1. Introduction

Due to the increasing demand for vehicles and transportation systems, new traffic control technology, and sufficient infrastructures for transportation, traffic congestion, and traffic delay are critical problems in many cities. This results in loss of travel time beside huge societal and economic costs. Artificial Intelligence (AI) techniques are used to solve these types of problems. The development of artificial intelligence traffic control approaches is one of the promising technologies that might improve road capacity, improve traffic light performance and reduce vehicle delay by adjusting parameters such as cycle, splits, phase sequences and offsets per change of the traffic volume.

II. Intelligence Traffic Control Systems

Due to the increasing demand for vehicles and transportation systems, new traffic control technology, and sufficient infrastructures for transportation, traffic congestion, and traffic delay are crucial problems in many cities. This results in loss of travel time beside huge societal and economic costs. Artificial Intelligence (AI) techniques are used to solve these types of problems. The development of artificial intelligence traffic control approaches is one of the promising technologies that might improve road capacity, improve traffic light performance and reduce vehicle delay by adjusting parameters such as cycle, splits, phase sequences and offsets per change of the traffic volume. The most famous and important artificial traffic control systems are (fuzzy, and neural network traffic light control systems). The existing applications of AI in traffic signal timing and optimization are primarily based on evolutionary algorithms, fuzzy logic control, artificial neural networks, and reinforcement learning algorithms. This paper will discuss and summaries the Fuzzy Logic Traffic Control Systems and Artificial Neural Network Traffic Control Systems. Also, the studies that are related to the artificial traffic control system are presented in this paper. Some points will be highlighted for future researches.

A. Fuzzy Logic Traffic Control System

Fuzzy logic control is a powerful tool for processing complex, non-linear and non-deterministic traffic control problems. The Fuzzy control system provides an intelligent green interval response based on dynamic traffic load inputs. The fuzzy control system used to model expert's thinking in situations where the development of a mathematical model is very difficult. On the other hand, Fuzzy logic allows using defective information practically to reduce the complexity of control systems and can be implemented in hardware, software, or a combination of both. The control process is shown in Fig.1.

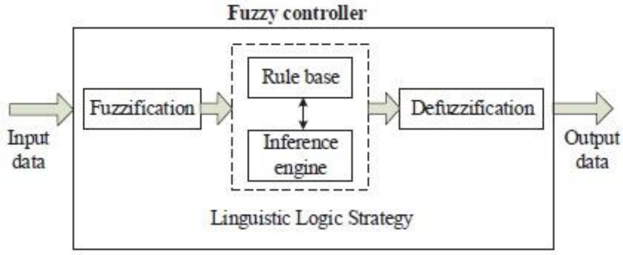

Fig.1: Fuzzy Control Traffic System Diagram [1]

B. Artificial Neural Network Control System

Artificial neural network (ANN) is one of the most important types of network systems that had been developed in 1940's by McCulloch and Pitts based on the organizational structure of the human brain neural structure through receiving information, storing them and combining them to solve problems. ANN system consists of inputs, which are multiplied by weights, and then manipulated by a mathematical function. The ANN system determines the activation of the neuron beside computing the output of the artificial neuron which is sometimes independent of a certain threshold, as shown in Fig.2 [2].

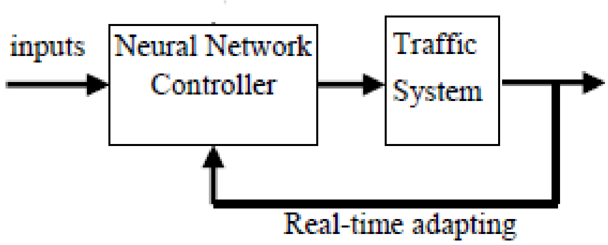

Fig.2: Neural Network Traffic System Diagram

C. Literature Review

During the last ten years, many studies had been conducted using fuzzy logic systems as follows: In 2013, Royani et.al [3] developed a fuzzy neural network on a real-time traffic signal at an isolated simple four phases intersection with expert knowledge to improve the traffic volumes in oversaturated and unusual load condition. A genetic algorithm was applied to adjust the developed system parameters by the learning process. Khan et.al [4] proposed a fuzzy control system for two traffic signals sated in a T-junction by using an image processing technique. The process linked to the fuzzy logic controller to generate a unique output for each input pattern by using the image process and fuzzy logic toolboxes of MATLAB. And, Zhou et.al [5] developed an adaptive traffic control system for a simple four phases intersection, in which the sequence of traffic signals can be adjusted dynamically by the real-time traffic data and the traffic signal length. Pour et.al [6] proposed a multi-objective algorithm model by using a fuzzy traffic signal controller for an individual two phases intersection with T-Type to optimize the timing of the traffic signal in oversaturated or unusual load conditions and to reduce the total traffic queue. The fuzzy theory is used to consider the uncertainty in the real world and the entrance and exit rates of an intersection. Furthermore, Stotsko et.al [7] developed a fuzzy algorithm traffic control system for a simply isolated intersection based on the existing traffic conditions by MATLAB software. The simulation results are shown that the developed fuzzy algorithm is used to reduce the average and maximal vehicle queue before the intersection owing to the adaptation of control system parameters to traffic volumes.

In 2014, Chao et.al [8] proposed a traffic control system based on radio frequency identification detection and ZigBee wireless network communication technology for network intersections by designing extension algorithm. Sensors are used to analyze the traffic information and to control the flow. The developed control system can perform remote transmission and reduce traffic accidents. And, it can effectively control the flow while reducing delay time and maintaining the smooth flow of traffic. Alam et.al [9] designed a fuzzy traffic signal control system for isolated 3-way T- intersection with a free left turn based on congestion estimation that is measured by sensors placed in each lane. Simulation software is developed and used to analyze the traffic signal controller efficiency. The results showed that the fuzzy system performed better than the fixed time or actuated systems. And, Alam et.al [10] developed a fuzzy traffic control system for simply isolated intersection with four phases to extend phases green time. The developed system is performed according to linguistic rules. MATLAB is used to simulate the developed system. The simulation results showed that the developed control system could improve the control system at intersections by reducing the traffic congestion and avoiding the time that wasted by a green signal on an empty road. Also, Kulkarni et.al [11] designed an adaptive control system based on a traffic infrastructure using wireless sensor network and dynamics techniques to control the flow sequences for simply isolated intersection with four phases and networks. A simulation system is proposed to measure the developed system performance based on the waiting time and average vehicle queue on the single intersection and thus, in turn, efficient network flow control on multiple intersections.

Furthermore, Sayyed et.al [12] designed an artificial intelligent traffic signal controller by having specific functions with hardware interface and fuzzy rules for four phases simple intersection. The first part of the program consists of data collection, sorting, calculation of percentage to use them for automatic evaluation of signal time. The second part is a web application that designed to provide traffic alerts for road users and take measures to avoid congestion. This system aimed to save a large amount of waiting hours caused by traffic gridlocks. Also, Jha et.al [13] developed a traffic model and traffic controller using MATLAB software based on queuing theory model for a multi-phases intersection with two lanes in each phase. The system is controlling based on the waiting time and vehicle queue at present green phase and vehicles queues at the other lanes. It is simple to construct using SIMULINK model, fuzzy inference system method, sim event toolbox and fuzzy toolbox in MATLAB. Also, the fuzzy logic traffic controller has emergency vehicle alert sensors, which detect emergency vehicle movement, and gives maximum priority to pass the preferred signal to it.

In 2015, Sandhu et.al [14] developed an intelligent-agent traffic model to control the amount of time a signal runs green based on vehicles density standing in the signal for the simple four phases intersection. The developed model smoothed the flow and reduced unnecessary delays. And, Caselli et.al [15] developed a swarm based traffic signals control system where each intersection controller makes independent decisions to improve the traffic performance of the network intersections. The control method is divided into macroscopic and microscopic control levels that react to the congestion length and the traffic density to act on the choice of the signal program or the development of the frame signal program. The simulation results showed that the proposed approach performance is like the fully actuated one. Yasar et.al [16] developed an artificial intelligent dynamic traffic signal control system with the support of artificial neural networks algorithm for a simple four phases intersection. A program has been developed by using a popular programming platform to calculate drive orders for traffic signals. Road traffic simulation software is used to verify the application output. The decision-making algorithm is designed to respond to certain traffic situations. Also, Wen et.al [17], Hui proposed an artificial intelligent traffic signal control system based on fuzzy logic controller and non-dominated sorting-based genetic algorithm. The fuzzy logic system is used to model nonlinear systems, and the NSGAII implemented to optimize both the fuzzy rules and the membership function parameters, as it can well optimize multiple objects simultaneously compared with other evolutionary algorithms. The proposed method applied to a six-intersections traffic network. Different traffic scenarios simulated and compared with each other. The results showed that the proposed control system got better performance than the other methods. Furthermore, Shah et.al [18] proposed a traffic control system to eliminate the phase time when vehicles are passing across and to reduce waiting time for a simple four phases intersections. The control

system is developed by using wireless sensor network to monitor and measure the vehicle number and road speed in real time. The simulation process showed a high performance of the developed control system.
In 2016, Jina et.al [19] introduced a fuzzy artificial intelligent traffic control system for isolated simple four phases intersection. The developed control system programmed with a capability to receive messages from the signal controller during real-time operations. Results showed that the developed control system has the potential to improve traffic mobility due to its ability in generating flexible phase structures and making timing decisions. A microscopic traffic simulation framework is developed to evaluate the developed control system.

3. Existing System

The signal control system strategies that are used in Kuwait to control the flow and vehicle movements are; Fixed time and semi-actuated control systems. The order and sequence of the phases are fixed in the fixed time control system and may vary under certain situations within the actuated control system. The traffic signal timing plans are generated in Kuwait by a Synchro program, where each intersection has individual timing and phasing strategy. The block diagram for the existing system structure in Kuwait is shown in Fig.3.

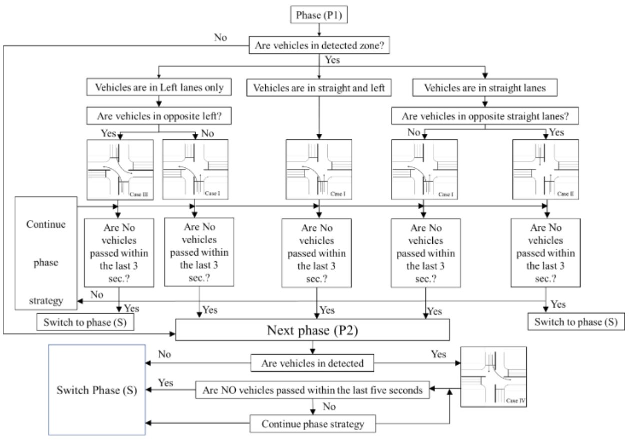

Fig.3: Existing Traffic System Structure in Kuwait

4. Proposed System

Traffic is a major concern for most cities especially crowded cities. The proposed intelligent traffic control (ITC) system is designed to solve some of these concerns. The proposed (ITC) system is designed based on the principle being that the vehicle can move ahead only if there is a space for passing. Sensors are placed at every entry and exit of the intersections to counting the number of cars passing the intersection. To achieve that, the proposed (ITC) system is designed as a dynamic system through four phases as shown in Fig.4:
Phase 1**:** Design of the green time distribution models,
Phase 2: Design of the fuzzy rules for selection of signal timings,
Phase 3: Initialization of the control system, and
Phase 4: Execution of the developed control system.

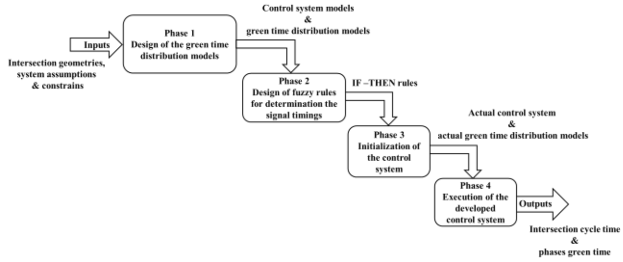

Fig.4: Phases of Designing the Developed Control System

A. Phase 1: Design of the Green Time Distribution Models

Several steps were applied to design the green time distribution models as follows:

Step 1 (Intersection specifications), All parameters like intersections geometries, roads types, and speed, in addition to the vehicle movement strategies, traffic devices, control and artificial systems are reviewed, studied, and analyzed.

Step 2 (Model assumptions and constraints), Based on the intersections reviews, the system assumptions and constrains were specified as follows:

- The control system is designed for an unsynchronized simple intersection with four perpendicular phases. Each phase consists of three vehicle movements as straight through, left, and right turns.
- The control system is designed for all traffic conditions (under saturation, saturation, and over saturation).
- The system is developed based on the flow that arrives and departs in the deterministic, uniform and steady way and distributed equally on the phases lanes.
- The distance between the intersections (L_d), ranged between $(L_d)_{max}$ = 2400 m and $(L_d)_{min}$ = 800 m.
- The distance length between two intersections is divided into several zones (Z). The minimum distance length unit zone (Z_{unit}) = 800 m, and the last zone of the intersection phase is critical zone ($Z_{critical}$).
- The vehicle length to be used in system calculation is specified as a medium personal vehicle with length (V_l) = 7.5 m.

The timing parameters (cycle time, maximum and minimum phase green time, red clearance time and the queue detector location) for each road type and speed are specified as shown in Table 1 [20].

Step 3 (Development of control systems), Seven control systems are developed based on intersection roads type (collector, major arterial, and minor arterial) as shown in Table 2.

Table 1: Intersections' Roads Specifications and Timing Parameters

Specification	Collector Road	Major Arterial Road	Minor Arterial Road
Road speed (km/hr)	40	80	50
Cycle length, T_{cycle} (sec.)	120	210	180
Maximum green phase time, $(T_\phi)_{max}$ (sec.)	$20 \leq (T_\phi)_{max} \leq 40$	$50 \leq (T_\phi)_{max} \leq 70$	$30 \leq (T_\phi)_{max} \leq 50$
Minimum green phase time, $(T_\phi)_{min}$ (sec.)	$6 \leq (T_\phi)_{min} \leq 10$	$9 \leq (T_\phi)_{min} \leq 15$	$6 \leq (T_\phi)_{min} \leq 10$
Red clearance time, T_c (sec.)	2	2	2
Queue detector location, d_q (m)	77	108	77

Table 2: Seven Control System Models

System No.	Control System	Direction			
		S'	N'	E'	W'
1	Collector	Collector	Collector	Collector	Collector
2	Major Arterial	Major Arterial	Major Arterial	Major Arterial	Major Arterial
3	Minor Arterial	Minor Arterial	Minor Arterial	Minor Arterial	Minor Arterial
4	Arterial Mix1 (Major + Minor)	Major Arterial	Major Arterial	Minor Arterial	Minor Arterial
5	Arterial Mix2 (Minor + Major)	Minor Arterial	Minor Arterial	Major Arterial	Major Arterial
6	Mix1 (Minor arterial + Collector)	Minor Arterial	Minor Arterial	Collector	Collector
7	Mix2 (Collector + Minor arterial)	Collector	Collector	Minor Arterial	Minor Arterial

Step 4 (Developing the green time distribution models), The models consist of green phases timing. These timing parameters; T_{cycle}, $(T_\phi)_{min}$, $(T_\phi)_{default}$, $(T_\phi)_{max}$ and the specified T_c for the seven control systems are presented in Table 3. These procedures are applied for developing 81-green phase time distribution models for each control system model (7 models).

Table 3: Timing Parameters for the Seven Control Systems

Control System Model	Collector			Major Arterial			Minor Arterial			Arterial Mix 1 (Major + Minor)			Arterial Mix 2 (Minor + Major)			Mix 1 (Arterial Minor + Collector)			Mix 2 (Collector + Minor Arterial)		
Maximum cycle time (sec.)	120			210			180			195			195			150			150		
Clearance time (sec.)	2			2			2			2			2			2			2		
Two phases road type	Collector			Major Arterial			Minor Arterial			Major Arterial			Minor Arterial			Minor Arterial			Collector		
Minimum green phase time (sec.)	6			9			6			9			6			6			6		
Default time (sec.)	10			15			10			15			10			10			10		
Zone No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Maximum green phase time (sec.)	20	30	40	50	60	70	30	40	50	50	60	70	30	40	50	30	40	50	20	30	40
Two phases road type	Collector			Major Arterial			Minor Arterial			Minor Arterial			Major Arterial			Collector			Minor Arterial		
Minimum green phase time (sec.)	6			9			6			6			9			6			6		
Default time (sec.)	10			15			10			10			15			10			10		
Zone No. (Z)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Maximum green phase time (sec.)	20	30	40	50	60	70	30	40	50	30	40	50	50	60	70	20	30	40	30	40	50

B. Phase 2: Design of Fuzzy Rules for Determination the Signal Timings

Step 5, A set of fuzzy rules are designed for the determination of signal timing by selecting the actual green time distribution model, and by calculating the intersection timing parameters.

C. Phase 3: Initialization of the Control System

Step 6 (Data inputs), There are several inputs are specified to be used in different steps based on their calls and functions in the selection and actual run processes. These inputs are; Intersection roads type to be used for selection of the control system model, length distance (L_d) to be used for selection of the green time distribution model, number of lanes (n_ϕ) and vehicle length (V_l) to be used for running process, and finally the clearance time (T_c) to be used for modification process.

Step 7 (Selection of the control model), The system is processing the intersection roads type (input) by the first set of the fuzzy rules to select the actual control model.

Step 8 (Calculation of the number of zones), The system is calling the length distance (L_d) and calculating the number of zones at each intersection phase.

Step 9 (Selection of the green time distribution model), The system is processing the calculated number of zones by the second set of fuzzy rules (5A.2) and selecting the actual green time distribution model.

D. Phase 4: Execution of the Developed Control System

Step 10 (Detection of the In and Out flow), The system is collection all data required using detectors.

Step 11 (Calculation of vehicle queues), The vehicle queue at intersection phase is formed by the vehicle residual through the cycles. The system at this step is calculating the vehicle residual using the following equation:

$$(R_{i+1})_\phi = (Flow_\phi)_{In} - (Flow_\phi)_{Out} + (R_i)_\phi$$

Where; $(R_{i+1})_\phi$: Number of the residual vehicle that is form in the cycle i+1, $(Flow_\phi)_{In}$: Number of vehicles that enter the intersection phase at the cycle time, $(Flow_\phi)_{Out}$: Number of vehicles that exit from the intersection phase at the green phase time, and $(R_i)_\phi$: Number of the residual vehicle from the cycle i.

After calculating the vehicle residual, the system is calculating the vehicle queue length at each intersection phase using the following equation:

$$Z_{\phi q} = \frac{(Ri+1)\phi}{n\phi} * V_l$$

Where; $Z_{\phi q}$: Vehicle queue length at the intersection phase (m), n_ϕ: Number of the lane at the phase, $(Ri+1)_\phi$: Number of the residual vehicle that is formed in the cycle i+1, V_l: Vehicle length (m).

Step 12 (Determination of the green phases and maximum cycle timings), At step 12, the system is processing the calculated vehicle queue by the fuzzy rules and determining the green phases times and the intersection cycle time.

Step 13 (Calculation of the total cycle time), The system is calculating the total cycle time using the following equation based on the green phases time and the cycle time that determined in step 12, and the clearance time for each phase is specified in the green time distribution models;

T_{total} = (TgS') + (TgN') + (TgE') + (TgW') + TcS' + TcN' + TcE'

Where; Tg: Green phase time (sec.) and Tc: Clearance time (sec.)

Step 14 (Modification of the green phases timings), The modification process is an important process in the control system that happens at the last phase clearance time, where the system at this step is processing the vehicle queues and their locations in the intersection phases with the relation between T_{cycle} and T_{total} by the fuzzy rules to modify and adjust the control system green phases times.

Step 15 (Activation of the traffic control processor), At this step, the system is giving the traffic signal the action for the next cycle timing.

Step 16 (Reporting of Outputs), The control system is providing a resulted report that includes intersection cycle time, green phases time, phases $(flow)_{In}$, phases $(flow)_{out}$ and vehicle queue to measure the developed control system performance.

5. Conclusion

The developed control system improves the vehicle flow by increasing the number of vehicles passing the phases and the number of vehicles passing the network directions. At the time, it reduced the green loss time from the phases with normal flow and added it to the phases where the traffic is high. Furthermore, the developed control system increased the number of cycles. The advantages of the developed control system are that the system distributes the green phases time based on the traffic situation dynamically. This control system is suitable for the simple four phases intersections that consist of the collector, major and minor arterial roads only, and cannot be applied on the intersections connected with highways. But, it is capable of building over a green time distribution models by adding the highway specifications. Also, the model is also capable of adding more fuzzy rules to combine between the vehicles queues at the phases of an intersection with the vehicle queues of the surrounding intersection phases.

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