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RESEARCH ARTICLE

Traffic Light Control in Vehicular Network Systems using Fuzzy Logic

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ABSTRACT

Vehicular concentration is getting worse in big and developed cities as we approach the year 2020, creating a challenge. Accurate traffic signal management is a key to efficient free traffic movement and increasing transport security levels. It is thus important to have traffic lights that change with the traffic intensity information that is collected in real-time. Thus, the objective of this study is to design a viable traffic signal control algorithm that would cause minimal delay to drivers. Building on the basis of fuzzy logic, the approach sets input attributes like the volume of the street and the queue of vehicles to identify the right traffic light settings. Performance criteria for evaluation include the average waiting time of the vehicles, and the findings of simulations in this regard show 21.7 seconds, which is faster than the benchmark formula of 25 seconds. This improvement is attributed to the fact that the fuzzy control system is adjustable.

Keywords: Average waiting time, Fuzzy logic, Traffic signal control algorithm, Traffic signal management.

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1. Introduction

Traffic congestion in cities has rapidly become a major problem around the globe due to which travel times have increased, fuel is consumed excessively, and there are also hazardous environmental implications. In order to deal with these problems, they Call Intelligent Transportation Systems or ITS. There is an ITS control for traffic signals; this is important for managing the traffic flow and time taken for commuting. Previously used traffic control systems are based on a fixed timing plan or least basic array of sensors that are able to identify the presence of vehicles at an intersection [1]. However, these methods do not take into account changing traffic conditions, and therefore, the traffic flow and the traveling time are not optimized.

In the last few decades, vehicular networks have transformed traffic signals by synchronously adapting and coordinating the timings of the Traffic signals and green Signal Durations based on the real-time data Coming from the connected vehicles. This research has suggested a highly specialized technique of incorporating fuzzy logic in a vehicle network-based traffic signal control system. Our technology, therefore, helps others decide whether to change the signal setup or how long a green light should be running, and all these under real-time traffic conditions. The integration of fuzzy logic improves the system's stability in processing data uncertainties and errors, which is even greater than the reliability of traffic control systems [2].

Current advancements in traffic congestion in the world's urban centers come with the following negative impacts: longer travel times, higher fuel consumption, and negative impacts on the environment. To eliminate these problems, Intelligent Transportation Systems (ITS) has proven to be a feasible solution. Integral to many ITS applications is the coordination of traffic signalization, which is essential for increasing the capacity of traffic signals and minimizing the time that the everyday commuter spends stuck in traffic [3]. Static approaches to traffic management, such as fixed timing plans or basic sensors used, perform poorly under dynamic traffic conditions as they are inflexible throughout and thus contribute to inefficient traffic flow and longer times on the road [4].

Due to these drawbacks, vehicular networks have emerged in recent years as a promising approach to traffic signal control. Making use of real-time information of connected vehicles, such networks allow the dynamic decision concerning signal timing and the period of green light. This paper suggests the implementation of a novel method incorporating a fuzzy system in the VSNS traffic control system. Regarding the indications, the proposed methodology of our work is aimed at analyzing the current traffic situation and adjusting signal timings and green light durations more effectively, thus avoiding redundancies or inefficient spending of time. The orderly integration of the new fuzzy logic also increases the capabilities of the system for data variations and uncertainties, making it more powerful and superior to standard traffic control systems [5].

Based on the literature review, to address this area, Intelligent Traffic Light Controlling (ITLC) is developed to optimally control each traffic signal phase concerning current traffic conditions [6]. The use of the ITLC algorithm has led to the creation of the Arterial Traffic Light (ATL) regulating algorithm in arterial street environments [7]. With the help of NS-2 simulations, the investigation of the performance of ITLC and ATL algorithms in the given situation is made [8]. As it is evident from the comparison with the Online Algorithm (OAF) traffic light scheduling method, ITLC has cut down the queuing wait and enhanced the traffic stream by 30% [9]. The introduced ATL regulating algorithm increases effective traffic signal control at arterial street intersections by 70% and decreases average delay by 10% compared to the ART-SYS traffic scheduling [4], [10].

Another objective of one of the studies is to develop a real-time traffic signal timing plan that relies on green phase fluxes with provisions for the emergency vehicle [11]. A new proposed strategy of adaptive traffic light control is whereby green light control on traffic signals at intersections is made to change depending on the real-time traffic flow information recorded; the method outperforms fixed-time and actuated control methods in terms of throughput and delay time [12]. The traffic management algorithm based on histories predicts traffic with histories showing an 18% enhancement in the traffic flow compared to conventional systems [13]. Sensors are used to form one large network spread out in space through which the traffic signals that regulate the movement of the traffic will have their phases modified dynamically and adaptively to yield the shortest waiting time [14].

The decentralized wireless sensor network method applicable to traffic light control offers a means for efficient traffic flow through traffic light regulations and expected changes in traffic density [15], [13]. The optimization of vehicle speed and signal control through V2I communication tries to have a perfect synergy between network throughput and the average speed of vehicles in order to increase operational efficiency [16]. Comparing one-sensor and two-sensor systems, it is clear that the systems with the optimized placement of two-sensor increase the effectiveness of traffic control in intersections [17].

An adaptive traffic control system utilizing Wireless Sensor Networks (WSNs) dynamically adjusts traffic signal flow sequences based on real-time traffic conditions, demonstrating effectiveness in reducing congestion [18]. Modeling of heterogeneous traffic networks using macroscopic models and logic constraints proposes adaptive traffic control strategies for signalized and non-signalized intersections [19]. Utilizing Vehicular Ad Hoc Networks (VANETs), researchers apply scheduling algorithms to minimize wait times at signalized intersections, demonstrating competitive performance compared to traditional methods [16].

A two-level approach using prohibition and warning signals is developed to manage urban traffic congestion caused by incidents, showcasing improvements in congestion dissipation through simulations [20].

2. Methodology

2.1. *Issue Framework*

The intersection model under consideration is a two-phase traffic signal setup with four streets depicted in the diagram. Streets 1 and 3 have synchronized traffic lights, meaning they share green phases. Similarly, Streets 2 and 4 operate with synchronized traffic lights. Street 3's traffic light becomes green concurrently with Street 1's traffic signal turning green. Streets 2 and 4 also follow a comparable synchronization pattern (Fig. 1).

A two-phase traffic light setup is shown in Fig. 2, with leg 1 and leg 3 denoting state 1 and leg 2 and leg 4 denoting state 2. The control variables are examined in the following manner within the framework of fixed-time fuzzy intelligent control: For intersection phase 1, (S-(1), S(-2), S-(3), S(-4)) = (0, 1, 0, 1) meaning that Street 2 and 4 have green signals, and Street 1 and 3 have red signals. This enables vehicles to move on Streets 2 and 4, and must halt on Streets 1 and 3. However, the initial states for phase 2 for the intersection are (S-(1), S-(2), S-(3), S-(4)) = (1, 0, 1, 0). This is because while Streets 2 and 4 have red light, Streets 1 and 3 have green light. Again, vehicles can operate on Streets 1 and 3 while the activities on Streets 2 and 4 cease. They make sure that the flow of traffic is well facilitated by observing corresponding green lights at the entrance of the intersection since the circulation of the car is harmonized to different phases that create less car backup at the intersection.

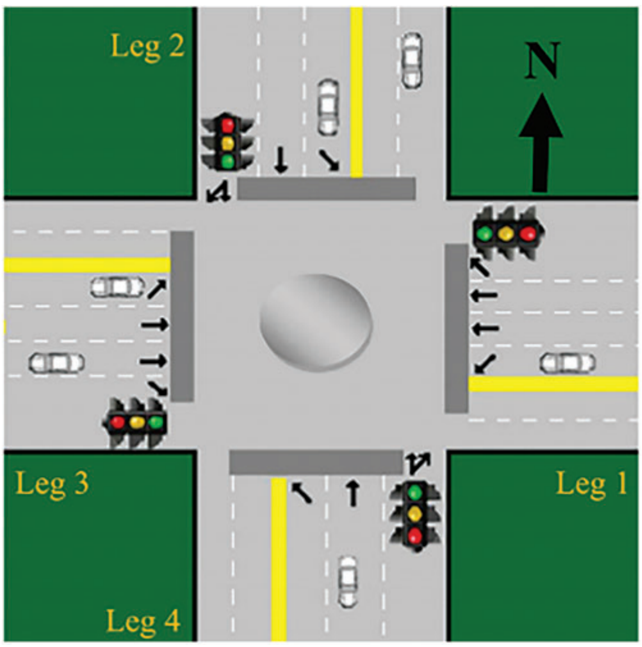

Fig. 1. Issue framework.

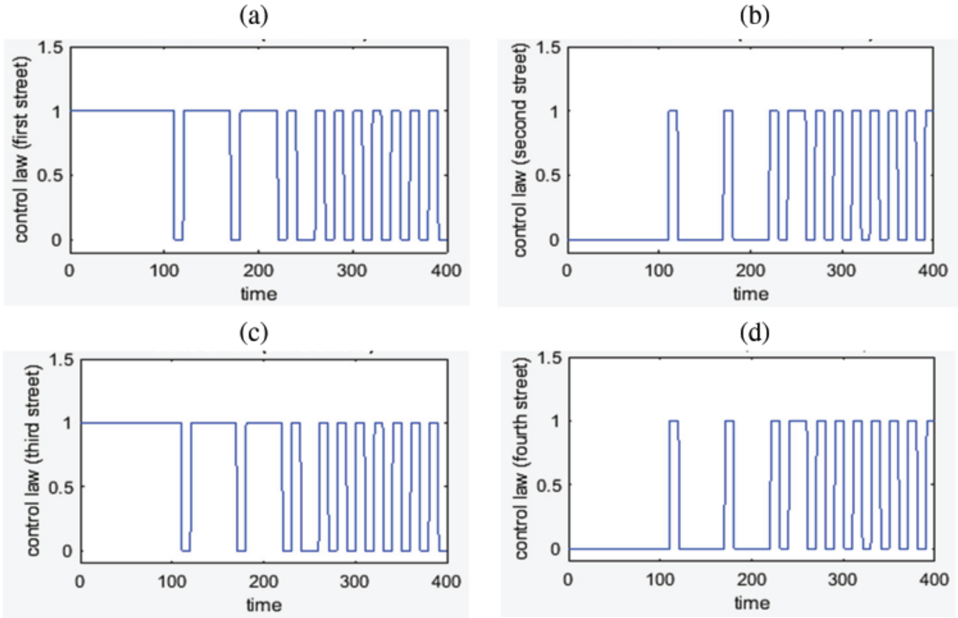

Fig. 2. Traffic signal management: (a) first street, (b) second street, (c) third street, and (d) fourth street.

TABLE I: The Problem Parameters

Description	Parameter
Number of the streets	nu_s
Discrete	TI
Queue length	Q L
Average waiting of time	WT
Uncertainty level	beta
Length of each the time index	T
Number of the cars passing	$d_i(n)$
This maximum number of cars value represents	Parameter for Saturation (d_const)
Signal of the state	s

2.2. *Determining Initial Parameters*

In regard with the proposed method, there are key parameters that must be defined to make the method more operational. These parameters include, among others, key aspects like the number of streets, length of the queue, mean waiting time, and many more that are critical in the modality of this research. By referring to Table I, it is seen that these parameters are explained in detail with significant elaboration, which provides the method's framework and assessment on which it is based. This provides order to the formulation of solutions to the intricate issues of traffic control and the identification of the best optimization strategies.

2.3. *Problem Formulation*

Formally, characterizing the problem of urban traffic signal control requires a decrease in the average queue length so that vehicle waiting times would be minimal. This queue length, $Q\_i\ (n+1)$, for each traffic flow i at discrete time interval n, is defined as this queue length, $Q\_i\ (n+1)$, for each traffic flow i at discrete time interval n, is defined as:

$$Qi(n+1) = Qi(n) + qi(n) - di(n) \cdot Si(n) \qquad (1)$$

where *i* stands for the traffic flow indices, and n is discrete time indices. $q\_i\ (n)$ stands for the number of cars in the *i-th* queue at time interval *n*, while $d_i\ (n)$ stands for the number of cars leaving the queue i in the same interval. $S_i\ (n)$ refers to the state of the signal for flow I, which is stop represented by 0 and go represented by 1.

The departing cars from queue *i* in time interval $n\ (d\_i\ (n))$ are determined by: The departing cars from queue *i* in time interval $n\ (d_i\ (n))$ are determined by:

$$di(n) = min(Qi(n) + qi(n), dsi(n)) \qquad (2)$$

where $d\_S_i\ (n)$ represents the saturation parameter, indicating the maximum cars that can exit queue *i* per interval, calculated as:

$$dsi(n) = dcons(n) + \beta qi(n) \qquad (3)$$

where $S_i\ (n)$ represents the saturation parameter, indicating the maximum cars that can exit queue *i* per interval. The uncertainty degree can be represented by β, which is a value between 0 and 1; $\beta = 0$ means the traveler is very certain, and $\beta = 1$ means the traveler has precise knowledge of journey time throughout the network.

3. Results

3.1. *Environment for Simulation*

MATLAB 2022b software was used to run simulations on a machine with an Intel Core i5 CPU. Further details are given in Table II.

3.2. *Evaluation Criterion*

In this study, the primary evaluation metric is the average queue waiting time. As mentioned previously, $Q(n)$ denotes the queue length, and the average waiting time W(n) can be determined using the average passage time per vehicle, ΔT, and the queue length $Q(n)$:

$$W(n) = Q(n) \times \Delta T \quad (4-1)$$

TABLE II: System Used in the Environment for Simulation

Item	Specifications
Processor	Intel Core "i5" (1135G7) 2.42 GHz
Main memory	(6.0 GB)
Hard disk	(256 GB)
OS	(Microsoft Windows 11)
Simulation software	MATLAB 2022a

3.3. Results Analysis

This section comprehensively analyzes the simulation outcomes of the proposed urban traffic control approach. It critically examines the results obtained from various experiments, highlighting key findings and insights derived from the simulations.

3.4. Examination of Traffic Signal Management

The traffic signal layout for controlling a four-street junction is shown in the diagram in Fig. 2. In this case, 0 represents a red light, and 1 represents a green light. Initially, traffic flow was uneven due to signals that gave preference to the first and third streets. Nevertheless, the traffic load eventually balanced, and the timings of the green and red lights on all streets synchronized with the help of a fuzzy controller. We will then go ahead and examine the state of each street independently (Fig. 2).

3.5. Analysis of First Street Traffic Conditions

The condition of the first street at an intersection is shown in the diagram below. The number of cars in wait behind the traffic light is displayed on the bottom area, while the top section displays the signal state. In the beginning, there was no queue, and the light was green. However, owing to heavy traffic, the signal went red after roughly 100 seconds, creating a backlog of nearly 13 automobiles. The fuzzy controller twice changed the signal back to green for this roadway as a result. As the graphic illustrates, the red light was activated often, which led to heavy traffic and expanding congestion. The controller needed around 280 seconds to stabilize the signal and keep it virtual (Fig. 3).

3.6. Examination of Traffic Situations on Second Street

The second street at a junction is depicted in the diagram below. There was a line while the signal was red at first. The red signal caused the queue to progressively grow from seconds 1 to 100. The queue was partially reduced when the light went green around 50 seconds later. But after taking into account the traffic patterns overall, the fuzzy controller changed the light back to red for this particular street. As shown, the controller needed around 280 seconds to properly stabilize and shorten the backlog. The signal stabilized at around 280 seconds, and the queue shrank, suggesting (Fig. 4).

3.7. Compare the Average Waiting Time of the Proposed Method with Other Approaches

Table III compares the average waiting times in stable states across different approaches. The observation yields a wait time between 41 seconds and 26 seconds, as indicated in the reference paper. In the reference case, the average delay at the traffic signals was 26 seconds while waiting for the change of signal status. On the other hand, for the proposed method in this study, the average waiting time measured only 22 seconds or an improvement of four seconds. This enhancement shows the capability of the aforementioned fuzzy logic-based approach to learn and improve traffic signal control.

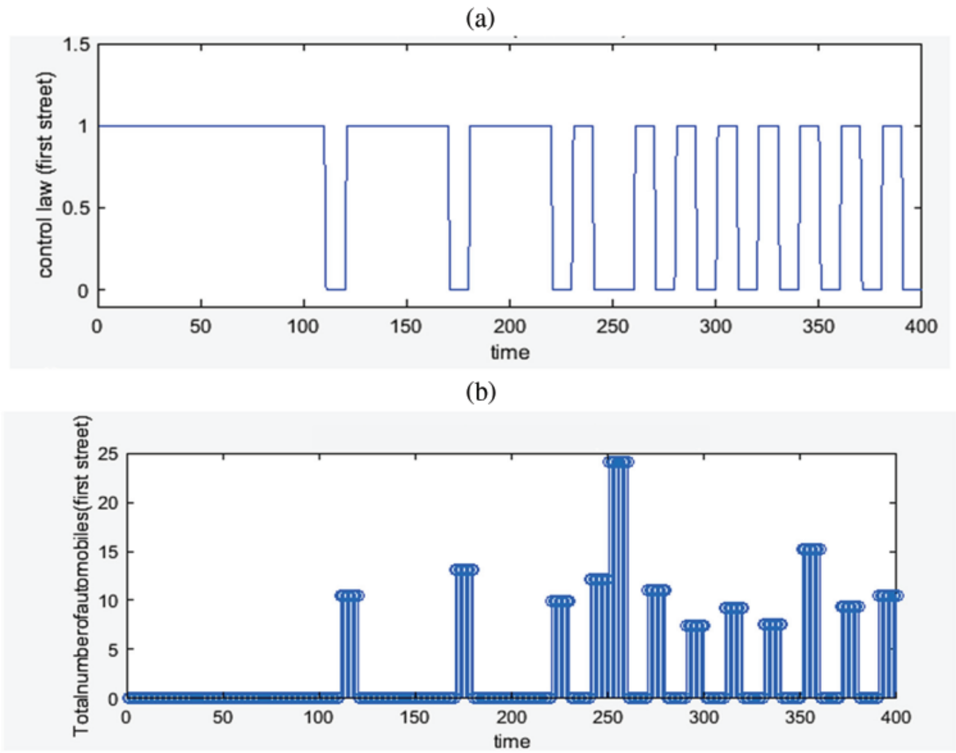

Fig. 3. Examination of traffic situations on first street: (a) control law and (b) total number of automobiles.

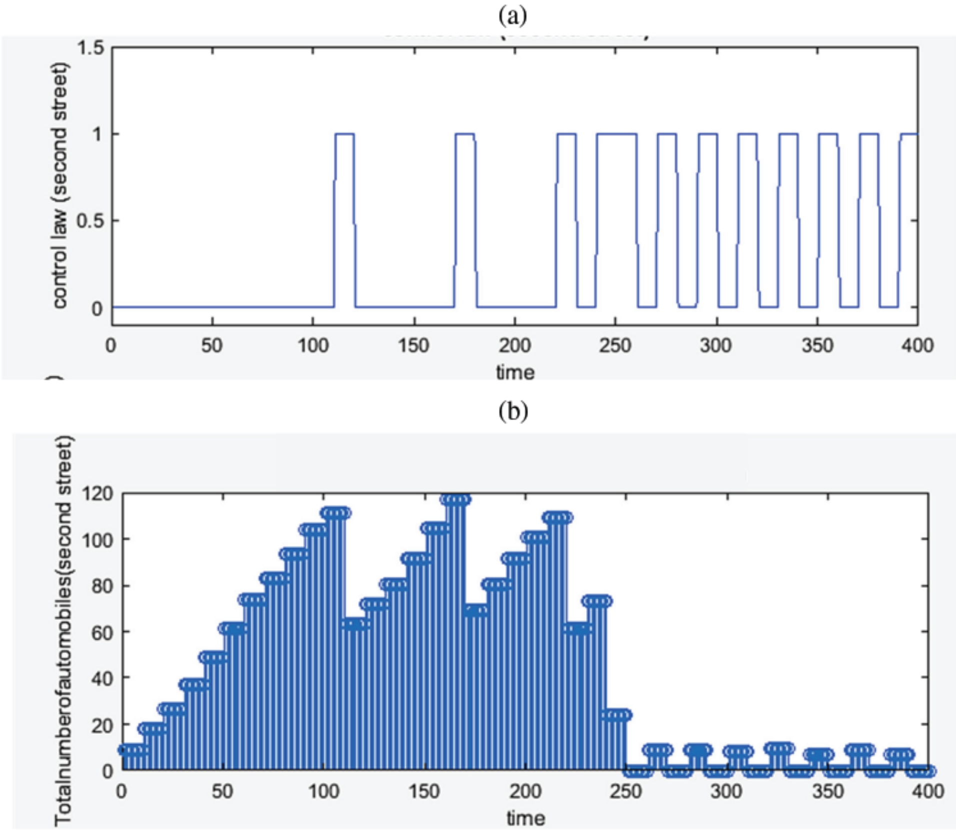

Fig. 4. Examination of traffic situations on second street: (a) control law and (b) total number of automobiles.

TABLE III: Comparison of the Results of Average Waiting Time

Average waiting time in a stable state (S)	Method
41	F-T T S
35.5	(FTTS)
32	(ATSC)
35	Deep of Q network
26.5	The reference of article method
22.1	The proposed method

4. Conclusions

The use of (fuzzy logic) in traffic signal control has significantly improved signal timing and reduced vehicle waiting times. The new system has shown a notable improvement, reducing the average waiting time from 25 seconds to 21.7 seconds compared to previous methods. The automatic adjustment of traffic signals based on data from connected vehicles (Vehicular Ad Hoc Networks) enhances traffic management efficiency. This approach helps in reducing wait times and delays compared to traditional fixed-timing methods or basic sensor-based systems. MATLAB software was used to monitor performance and simulation results, demonstrating that the proposed system effectively reduces waiting times and improves traffic flow at a four-street intersection. The system's ability to adapt to changing traffic conditions and handle uncertainties highlights its stability and efficiency. When compared to other methods, the proposed approach reduced average waiting times to 22.1 seconds, while other approaches had waiting times ranging from 26 seconds to 41 seconds. This indicates that the fuzzy logic-based method is more effective in managing traffic signals. The study represents a significant step forward in traffic signal management by leveraging Intelligent Transportation Systems (ITS). These systems use real-time data from connected vehicles to improve signal coordination, enhance the driving experience, and reduce delays.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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