Hybrid Intelligent Traffic Signal System: Al-Muthana Intersection in Baghdad as a Model

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ABSTRACT

Day after day, the problem of vehicular traffic congestion is increasing especially in urban areas and large cities, which exhausts most road users around the world. Baghdad is one of the large and densely populated cities that has suffered from stifling crowding in the last ten years. The basic reason of this problem is the exponential increase in the number of vehicles and the corresponding basic design that the streets previously adopted, while it was designed more than fifty years ago to accommodate 10% of the number of vehicles existing today which can no longer serves these huge numbers of vehicles.

The current technology system that used at the assigned intersections of Baghdad is depending on giving priority to traffic on statistical data received from cameras installed at the intersections only, without take the considerations into numbers of vehicles heading to the intersection from the four directions.

This paper suggested a hybrid technique to the current system which improve the traffic flow and reduces congestion by assigning an appropriate amount of green light to each phase and adding an extra amount of green light according to the statistical data of vehicle numbers that received from the new hybrid system.

The suggested hybrid system determines the most crowded path by using two methods of vehicles counting. They are the Digital Vehicle Counting (DVC) and the Manuel Vehicle Counting (MVC) methods. One hundred meters is assigned as an effective detection zone away in the four directions from the traffic intersection. The comparison is performed between the counting values of hybrid counting method that receives from each direction at the traffic phase router (TPR). The chance is given to the direction with the highest vehicle counts to leave the intersection within a suitable time amount.

The proposed hybrid system was simulated using python software. Implementation of hybrid system simulation proved that the proposed system performed better than the existing system based on the Key Performance Indicators (KPIs) used.

Keywords: Hybrid Traffic Signals, Traffic Congestion, Urban Traffic Control, Vehicle Counting, Traffic Signal Optimization.

نظام إشارات المرور الهجين الذكي: تقاطع المثنى في بغداد انموذجا

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الملخص

تتزايد مشكلة الازدحام المروري يوما بعد يوم وخاصة في المناطق الحضرية والمدن الكبرى والتي تجهد معظم مستخدمي الطرق في العالم. وتعد بغداد من المدن الكبيرة والمكتظة بالسكان والتي عانت من الازدحام الخانق في السنوات العشر الماضية. والسبب الأساسي لهذه المشكلة هو الزيادة الهائلة في عدد المركبات ويقابله التصميم الأساسي الذي اعتمدته الشوارع سابقا، في حين أنها صممت قبل أكثر من خمسين عاما لاستيعاب ١٠% من عدد المركبات الموجودة اليوم والتي لم تعد قادرة على خدمة هذه الأعداد الضخمة من المركبات.

إن نظام التكنولوجيا الحالي المستخدم في التقاطعات المخصصة لبغداد يعتمد على إعطاء الأولوية لحركة المرور على البيانات الإحصائية الواردة من الكاميرات المثبتة في التقاطعات فقط، دون الأخذ بعين الاعتبار أعداد المركبات المتجهة إلى التقاطع من الاتجاهات الأربعة.

اقترح هذا البحث تقنية هجينة للنظام الحالي تعمل على تحسين انسياب حركة المرور وتقليل الازدحام من خلال تخصيص كمية مناسبة من الضوء الأخضر لكل مرحلة وإضافة كمية إضافية من الضوء الأخضر وفقا للبيانات الإحصائية لأعداد المركبات الواردة من النظام الهجين الجديد.

يحدد النظام الهجين المقترح المسار الأكثر ازدحامًا باستخدام طريقتين لحساب المركبات. وهما طريقة العد الرقمي للمركبات (DVC) وطريقة العد اليدوي للمركبات (MVC). يتم تعيين مائة متر كمنطقة كشف فعالة بعيدًا في الاتجاهات الأربعة من تقاطع المرور. يتم إجراء المقارنة بين قيم العد لطريقة العد الهجين التي تستقبل من كل اتجاه عند موجه مرحلة المرور (TPR). تُمنح الفرصة للاتجاه الذي يحتوي على أعلى عدد من المركبات لمغادرة التقاطع في غضون فترة زمنية مناسبة.

تم محاكاة النظام الهجين المقترح باستخدام برنامج (paython). أثبت تنفيذ محاكاة النظام الهجين أن النظام المقترح كان أداءه أفضل من النظام الحالي بناءً على مؤشرات الأداء الرئيسية (KPIs) المستخدمة.

الكلمات المفتاحية: الإشارات المرور الهجينة، الازدحام المروري، التحكم في حركة المرور في المناطق الحضرية، عد المركبات، تحسين الإشارة المرورية

Introduction

The hasty growth of urbanization has amplified the conflict between road traffic supply and request, resulting in severe traffic congestion, especially at intersections. Intersections are critical components of urban road networks where vehicles frequently merge, diverge, and cross, creating complex traffic conditions. The increasing number of vehicles of all types and size, along with outmoded infrastructure and inadequate traffic management, has made congestion at intersections a major problem, affecting urban mobility and the capacity of the road network [1,2,5,11]

Many traditional methods of traffic management, such as phase design and optimization of signal cycle length, have long been used to improve intersection capacity. However, these methods often fall short in effectiveness due to the induced demand effect, this phenomenon occurs when increased road capacity attracts more vehicles, ultimately leading to renewed congestion. As a result, the solutions that only depend on infrastructure-based are no longer considered effective for long-term congestion mitigation [3,6].

To face these challenges, intelligent traffic signal control systems have been developed by many researchers. They focused on optimizing signal timing to decrease travel delays, vehicle stops, and total congestion. Y. Shinde and H. Powar used Infra-red sensors to collect the data of vehicles traffic and feed it to a control unit. The implementing of the system was easy but these sensors lacked capability to discriminate between walkers and other objects from vehicles, so it wasn't entirely accurate [7]. While, H. Chaudhuri and N. P. Raikar Combined GSM technology and ultrasonic sensors to control traffic flow at an isolated intersection. The system characterized by consuming less power but for guarantee the effective operation, a periodic checking of accuracy and precision is essential [8]. In [9] they used pneumatic tube sensors. The variation in the number of axles for the trucks and the big bus leads to a major imbalance in the system. The proposed systems in [10] gives a much more precise statistics comparing to the other usually used techniques but the implementation is very expensive. Another study proposed three synchronization procedures to improve traffic light control at intersections. When the negotiating vehicles arrive, the ICANP first stops the green timer for the regular vehicle phases to give the negotiating vehicles the chance to pass quickly through the indicated intersection [12].

Some of these systems utilize real-time data and sophisticated algorithms to dynamically adjust signal timings based on traffic situations. The integration of these intelligent systems into urban traffic management has shown promising results in enhancing intersection efficiency and reducing congestion impacts [4].

In this paper, a hybrid intelligent traffic signal system is proposed specifically designed for the Al-Muthana Intersection in Baghdad Fig (1). The proposed hybrid system integrates (DVC) and (MVC) techniques within a (TPR) to assign green light durations dynamically based on a comparison of the received reading from (DVC) and (MVC) of vehicle counts in the target intersection zone. By operating within a 100-meter detection zone on the four lanes heading towards the intersection, the system effectively manages traffic flow from all directions by give priority to the most congested lanes and adjusting signal timings accordingly.

The hybrid system proposal is restricted to directing traffic flow at an isolated intersection and conduct a proficiency testing in a virtual simulation environment.

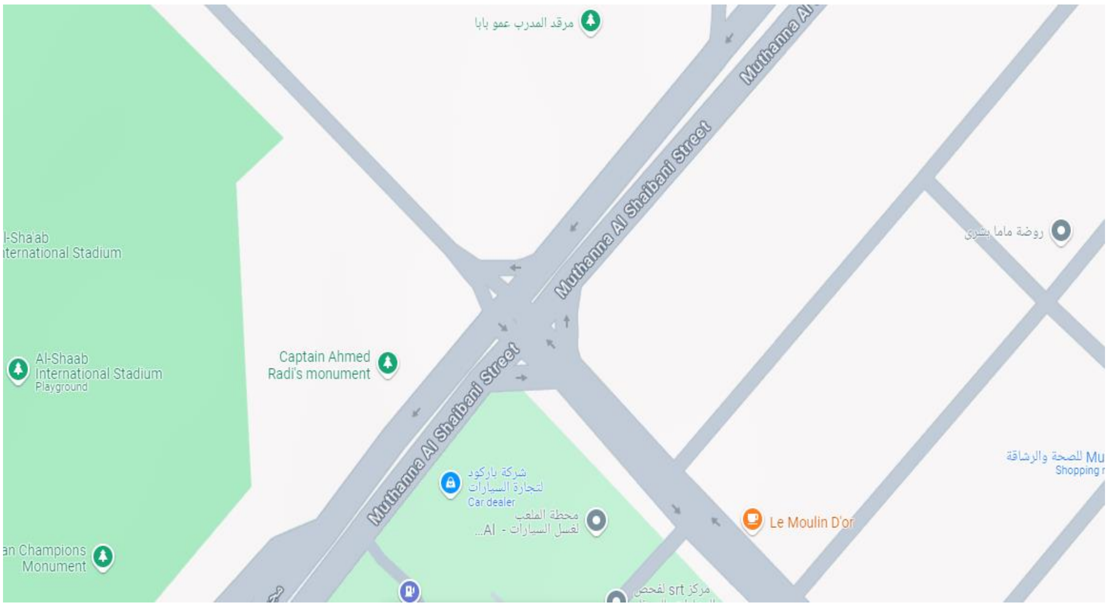

Figure (1): Image from Google Maps of Al-Muthanna Intersection

Data Collection

We are assigned Al-Muthana intersection in Baghdad as a module for the simulation of the proposed hybrid technique, where it is considered one of the vital intersections and was recently equipped with an intelligent traffic light system.

Data were collected during three key periods: morning, afternoon, and evening, which correspond to peak traffic hours due to work schedules in government institutions and private companies, as well as increased evening activities.

The data collection involved assessing various time-based visual data, including traffic maps and congestion level plots, at random intervals to capture a comprehensive traffic pattern. This approach allowed for the identification of key congestion periods and provided insights into traffic dynamics at the intersection.

Table (1) show data collected at the selected intersection:

The direction	session	Number of session hours	Number of vehicle arrival per hours	Number of vehicle departure per hours
From Palestine intersection to Al-shaab bridge	Morning	3 hours 7am-10am	450-500	350-400
From Palestine intersection to Al-shaab bridge	Afternoon	2 hours 1pm-3pm	٢٧٥-٢٥٠	٢٢٥-٢٠٠
From Palestine intersection to Al-shaab bridge	Evening	3 hours 5pm-8pm	٢٧٥-٢٢٥	٢٥٠-٢٢٥
From Al-shaab bridge to Palestine intersection	Morning	3 hours 7am-10am	250-300	250-300
From Al-shaab bridge to Palestine intersection	Afternoon	2 hours 1pm-3pm	500-550	450-475
From Al-shaab bridge to Palestine intersection	Evening	3 hours 5pm-8pm	375-425	325-350
From Al-rubaie intersection to the traffic police street	Morning	3 hours 7am-10am	150-175	150-160
From Al-rubaie intersection to the traffic police street	Afternoon	2 hours 1pm-3pm	75-100	75-100

From Al-rubaie intersection to the traffic police street	Evening	3 hours 5pm-8pm	75-100	75-100
From the traffic police street to Al-rubaie intersection	Morning	3 hours 7am-10am	75-100	75-100
From the traffic police street to Al-rubaie intersection	Afternoon	2 hours 1pm-3pm	100-150	100-125
From the traffic police street to Al-rubaie intersection	Evening	3 hours 5pm-8pm	25-50	25-50

PROPOSED SYSTEM

The proposed hybrid system combines two techniques to count the number of vehicles within the effective detection area (Al-Muthana Intersection). (Figure 1)

These two techniques are the Digitally Vehicle Counting technique (DVCT) and the Manually Vehicle Counting technique (MVCT).

We will consider the intersection of Al-Muthana zone as an isolated area where system operations take place, so obviously vehicles are ignored outside this area. The notion is to consider the specific closely area to the intersection and spread it to the whole lane.

It is self-evident if the detection area (specified by one hundred meters away from the traffic intersection at each of four direction) is less jammed or traffic free, which also supposed to match the whole lane. The primary mode for counting vehicles is Digital Vehicle Counter (DVC) which contains four cameras, one for each lane. Each camera is responsible for observation and shooting vehicles within the detection zone. The cameras count vehicles through an intelligent system that analyzes the captured images from the traffic scene in the covered lane. The values obtained from each lane are passed to traffic phase router (TPR). (TPR) is programmed basically to give the green light priority at system initialization, according to the vehicle counting received from the DCVT, then give the green light by turning on the four lanes in a clockwise direction.

(TPR) after assigned the lane with the highest vehicle counting, wait to receive the data from (MCVT). (MCVT) consists of laser sensors for each lane that is mounted on a horizontal beam installed at a suitable height, across the width of the street, 100 meters away from the intersection and at both the entry and exit points of the detection zone. When a vehicle drives under the sensors, the sensors detect the entry and exit of vehicles. The received data from (MCVT) is final result of subtracting the total exit sensors data from the entry sensor data for the pre-assigned lane by (TPR). (TPR) then performs a comparison between the (DCV) data and the (MCV) data, if the result of the comparison is (DVC < MCV) then green light signal assigned for (90 second), while if (DVC ≥ MCV) then green light signal assigned for (180 second) for the lane. The last process after the green light signal time has expired is lighting red signal and moving to the next lane clockwise.

It should also be noted that the red signal is given directly to the lane if the (DCV) reading is zero.

Fig (2) below clarifies the algorithm used by the (TPR) to allocate green phase time for each lane according to the above proposed system.

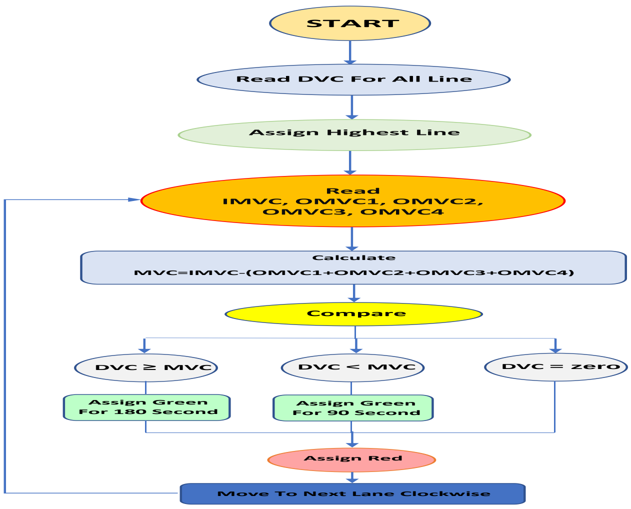

Figure (2): Proposed Algorithm

SIMULATION RESULTS

This section evaluates the efficiency of the proposed hybrid intelligent traffic signal system using specific (KPIs) to assess its impact on traffic congestion at the Al-Muthana Intersection. The (KPIs) selected for this study include average vehicular speed, average trip duration, and average trip queuing time. The (KPIs) are essential criterions for the performance comparation of the current system with the performance of the proposed system in managing traffic flow. The main aim of the hybrid proposed system is to reduce vehicular congestion at the intersection, thus improving traffic flow and total transportation efficiency.

The traffic management system was simulated before and after the proposed hybrid technique applied, and the selected (KPIs) were utilize to authenticate the proposed system efficiency. Significant improvements were indicated, in traffic flow and congestion reduction, with the proposed hybrid system simulation. Specifically, the increasing in average vehicular speed to 44.8%, which reflecting a substantial improvement in traffic flow efficiency at the intersection. The dynamic allocation of green light durations contributed greatly in this improvement, which reduces stop-and-go situations and allows vehicles to keep higher speeds through the intersection.

Additionally, the average trip queuing times was reduced by 29.2%, which leading to fewer delays for vehicles waiting to cross the intersection. This improvement was a result by prioritizing lanes with higher vehicle counts. Furthermore, the average trip duration achieves a 26.7% improvement, referring a more organized and efficient traffic flow through the intersection. This improvement implies reducing the total time vehicles spend traveling through the intersection, including both moving time and time spent waiting at signals.

Table (2) summarizes the (KPIs) which used to evaluate the actting of both the existing and proposed systems, along with their respective units of measurement and comparative results.

Key Performance Indicator	**Unit**	**Existing System**	**hybrid System**	**Improvement percentage**
Average Vehicular Speed	[m/s]	4.5	6.5	44.8%
Average Trip Queuing Time	[s]	65	46	29.2%
Average Trip Duration	[s]	150	110	26.7%

The closely look at the results listed in the table (2) it shows that the proposed hybrid traffic signal system effectively reduces traffic congestion and enhances vehicular flow at the Al-Muthana Intersection. The results support the scalability of the proposed system to involve other urban intersections with similar traffic challenges, relying on collecting data and statistics for traffic flow in and around the intersections in more than one technique, especially modern one, has become an established approach to solving the problem of traffic congestion.

The improvements in traffic flow not only shortness travel times and enhance the mobility experience for drivers but also Contributing to achieving broader goals of urban mobility, such as reducing fuel consumption and lowering emissions

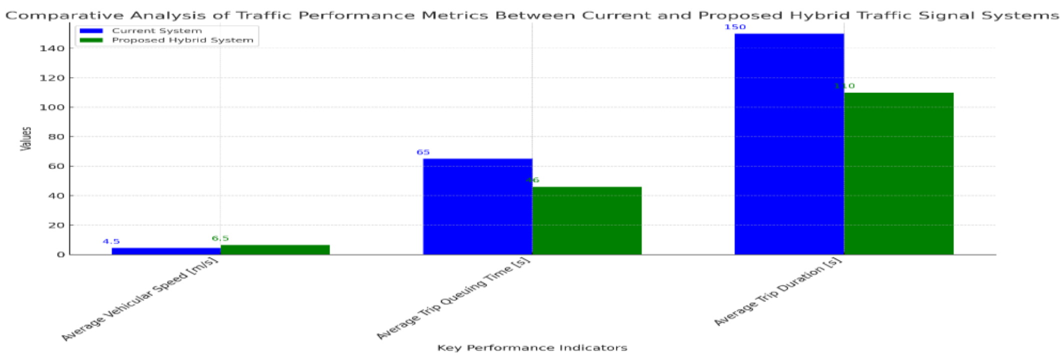

Figure (3): Comparative Analysis of Traffic Performance Metrics Between Current and Proposed Hybrid Traffic Signal Systems.

Fig (3) provides a visual comparison of the current and proposed systems across the selected KPIs, highlighting the improvements achieved by the proposed hybrid traffic signal system.

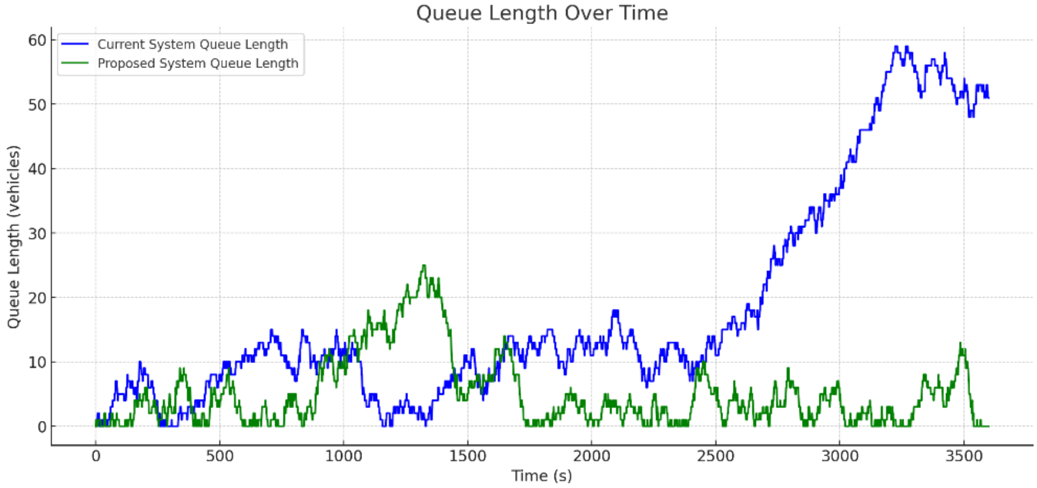

Figure (4): Queue Length Over Time for Current and Proposed Systems

Figure (4) illustrates the queue length over time for both the current and proposed systems. Clearly from the graph the proposed hybrid system preserves shorter queue lengths consistently throughout the simulation period compared to the current system.

The simulation also provides a more detailed analysis addition to the previous metrics were included to further evaluate the performance of the proposed system, we listed them quickly and leave them for the rest of the researchers to study:

1. **Intersection Delay:** The proposed system reduces total delay by 27.8%, highlighting its capability to minimize overall vehicle delays at the intersection.

2. **Intersection Throughput:** Increasing by 33.3%, indicating a higher count of vehicles that pass through the intersection efficiently under the proposed system.

3. **Stop Time per Vehicle:** Decreasing by 37.5%, reflecting smoother traffic flow with fewer stops and less indolent time.

4. **Fuel Consumption**: Reducing by 25.0%, demonstrating the environmental benefits related with traffic management improvement and reduced congestion.

5. **Emissions Reduction (CO2)**: Decreasing by 28.0%, contributing to lower environmental impact and air quality improvement.

6. **Number of Stops per Vehicle**: Reducing by 50%, showing a significant improvement in continuous vehicle movement through the intersection.

Conclusions

In this study, a hybrid traffic signal system is presented. The simulation of this system concluded the following: a significant improvement was noticed the in the traffic management for congested urban intersections. The hybrid proposed system has the ability to adjust signal timings dynamically based on real-time traffic, this efficiency is due to precisely choosing the distance of the sensors from the intersection to count the number of cars heading to the intersection.

The hybrid system offers a scalable and robust solution for modern traffic challenges in other intersections in Baghdad

Future research could explore the system's implementation in different urban contexts, as well as its integration with other intelligent transportation systems (ITS) technologies to further enhance its capabilities and impact.

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