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A Fog Based Smart Traffic Management System

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Abstract

Recently, urban mobility has become one of the most pressing issues in today's cities, and it must be addressed with caution. The exponential increase in the number of cars has a negative influence on the transportation system that most communities rely on. One of the most important aspects of transportation system is traffic control, which is reliant on a series of coordinated traffic lights. Smart traffic lights not only can receive and analyses the real time traffic data but also can help to alleviate traffic congestion by accurately predicting the waiting time for each traffic lane at the intersections. This can help to enhance traffic flow and, as a result, the overall performance of the transportation system. The proposed Smart Traffic System (STS) not only an automated IoT based traffic measuring system but it also calculates the ideal waiting time for each traffic lane. Calculating the optimal waiting time of each lane of the intersections can reduce the average waiting time. The objective is to provide accurately real-time traffic updates on traffic congestion according to the size of vehicles and their location relative to the traffic lights. Urgent cases for emergency vehicles also has been taken into consideration. Ultrasonic sensors and a lateral scanning approach are employed in the proposed STS which is suitable for using on real traffic roads in various roadway environments. STS adjusted to accurately measure traffic volumes according to the size of vehicles and their locations relative to the traffic light in real time. A prototype is implemented to evaluate the feasibility of the model. Simulation results show good accuracy in vehicles detection, low relative error in road occupancy estimation, the least delay, and highest throughput compared to other works.

Keywords: IoT, Traffic management, Traffic light, Smart city, Fog computing, Arduino, and Ultrasonic Sensor.

1. Introduction

Smart cities are urban environments where diverse sectors collaborate to produce consistent results by analyzing real-time or contextual data. This growth in the urban population, combined with growing urbanization, poses substantial issues for our society. As a result, a developing strategy for solving these difficulties while using the newest technical advancements to make cities smart is required [1]. Fog is a new paradigm which allowed a real time communication and helpful on making a fast decision particularly on internet of things (IoT) applications [2,3]. By the time, the number of vehicles are growing rapidly and the traffic congestion issue become more urgent. As all the modern devices have the ability to communicate over the internet like smart TVs, air conditioners, tablets, laptops, vehicles and etc. Transportation is no exception from that, people tend to use their cars for stepping out instead of waiting in crowded public transportation. Also traffic lights need to be smart to adapt with the requirements of the current era.

Congestion, fuel emissions, air pollution and energy losses should all be minimized in smart cities, while the effectiveness and quality of life within resource constraints should be improved [4]. Figure 1 presents some smart city required services and applications. Cloud computing is also used in the protocols used to implement smart cities [5]. As a result, smart cities have had to deal with the limitations and drawbacks of cloud computing, such as location awareness, inconsistent latency, and a lack of mobility support [3]. Fog computing [2] provides a number of answers to these issues. Many attempts have recently been undertaken in the realm of fog computing applications in smart cities [6]. A smart city's major goal is to improve the quality and efficiency of public services, especially transportation, by integrating information and communication technologies. Smart traffic lights tend to control, monitor, optimize, and operate the flow of traffic at road intersections and facilitates people's life. All the real-time data about the transportation system are uploaded to the fog to provide transport officials and consumers a real-time update about the city's transport availability and condition [8]. The growth in the urban population requires more effective solutions to overcome the transportation problem and promote new strategies to reduce traffic congestion. This study aims to propose a smart traffic system in smart cities. Cloud computing is a common method for offering a variety of services over the internet. Processing data away from local devices or the workplace is one of the benefits of cloud computing services. It offloads all of the work to huge and powerful computer clusters in the cloud. Cloud computing provides the ability of allowing data and apps to be accessed from anywhere in the world using any device connected to the internet. Fog computing extends the cloud computing definition to the network, making it appropriate for real-time and internet-of-things (IoT) applications [9]. Fog can establish a low-latency network between devices, which minimizes the amount of bandwidth required for communication when compared to cloud-based data transfer and processing. Its deployments make data transfer between different sites easier. Fog computing has a wide range of applications, including linked vehicles, smart grids, smart cities, and real-time analytics. There are a wide number of fog computing advantages including: (i) high processing speed: as fog computing performs the process at the network edge, where it is closest to the user, (ii) numerous nodes: which can store and process data, (iii) sufficient security and privacy: manipulating gathered data on-site reduces the likelihood of adversaries and attackers intercepting or compromising the data [10], (iv) location awareness: unlike cloud computing fog nodes are close to the data source and outputs could be used locally, Whole smart cities based on Internet of things (IoT) technology [7] as it is built relying on fog computing. Smart cities are usually interconnected which depending on data gathering, processing, and analysis for everything. IoT sensors are responsible for this function as they gather data from all the devices and upload it into a model where it can be processed and analyzed accurately. To get accurate and suitable decisions, IoT devices and platforms must be connected with each other [8]. To maintain effective connectivity, they must collaborate with network providers to establish stable connectivity points throughout the fog. IoT has provided numerous chances for large cities that have decided to implement new smart technologies in order to improve the quality of their operations. Intelligent traffic technologies have piqued people's interest in recent years. For traffic management, various approaches are available, such as ultrasonic sensors, infrared sensors, video data analysis, etc. The advancement of information technologies such as computing science, Global Positioning System (GPS) [11], mobile internet, vehicle-to-vehicle, vehicle-to-infrastructure, and autonomous driving has resulted in abundance of advantages for traffic data processing [12].

The aim of STS is to optimize the traffic system efficiency and performance, e.g., reducing pollution, noise, and transit times. STS presents a well-planned strategy for managing the traffic lights. There are many

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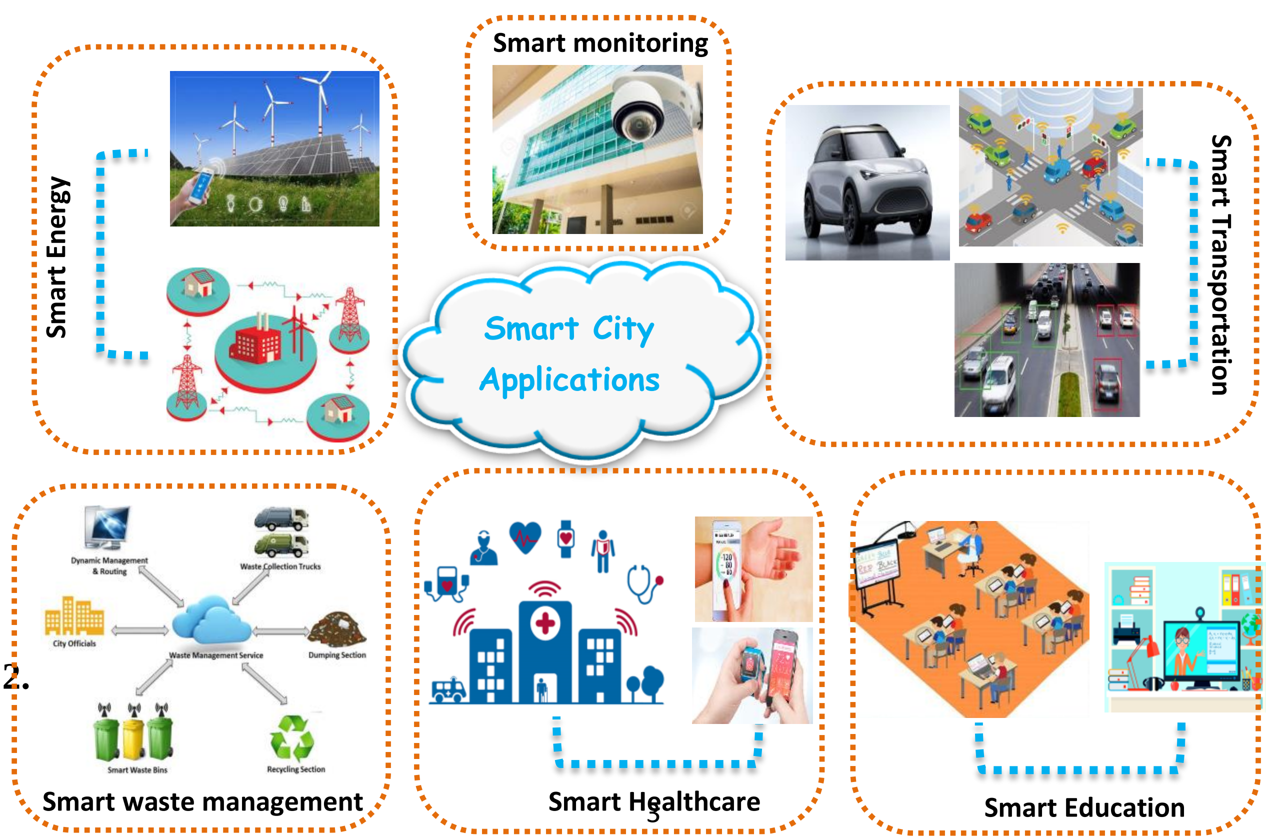
benefits of using STS to control the traffic lights, for example, there is no need to wait a long time for the traffic light to turn green while there are no vehicles or congestion in the street. Instead of work as a traffic controller this leads to accumulation of traffic congestion. STS gathers the real-time traffic data and transmits it to be analyzed in fog computing to get the optimal waiting time based on the number of waiting vehicles. All conditions of the road traffic must be calculated to control and manage traffic flows. The road traffic status can be described using number of parameters as the number of waiting vehicles in each lane and their size to provide a fair representation of the situation [13]. The length of the lane can be considered as a variable since it depending on the geometry of the road. Many techniques and strategies have been proposed to predict the optimal waiting time for traffic lanes to enhance the performance and efficiency of the traffic management system [12, 14]. However, sufficient results have not been achieved yet. A new smart solution is needed to be developed to overcome the traffic congestion problem. The main organ in smart management systems is the smart traffic light which responsible for minimizing the waiting time people spend for launching the green lights. Automated traffic reset can be achieved based on traffic patterns and ambient conditions changing which improve vehicle mobility. Also priority can be controlled and given to emergency vehicles which achieve better traffic control and therefore human safety and comfortability.
The contribution of this paper can be concluded in an advanced strategy to measure traffic congestion in the road and control traffic lights with the optimal waiting time, this processing based upon fog computing. The main objective of STS is to minimize traffic congestion and maximize the reliability of the traffic system by managing the waiting time for the waiting vehicles. This paper is organized as follows, section 2, some related works have been presented, in section 3, the proposed smart traffic system will be discussed. Section 4, shows the evaluation and simulation results. Finally, the paper is concluded in section 5.



2.

Figure 1: Smart city Services

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Since traffic flooding has an impact on people's daily lives in the country, it must be properly managed. There are many works related to traffic management approaches to develop smart traffic light systems to limit the traffic congestion. This section focuses on recent advances in intelligent traffic management research, such as system models for traffic updates, traffic congestion measures, emergency vehicle handling, and calculating the optimal waiting time for each lane in the intersections. Table 1, investigates some recent smart traffic light algorithms. The proposed system in [15] used Q learning algorithm based on fog computing to reduce and control the traffic congestion. Authors in [16] proposes a multi-agent system (MAS) strategy for intelligent urban traffic management based on classification and forecasting techniques. While [17] proposed a Fuzzy Logic controller system to schedule traffic lights in a single intersection to reduce the queue length with precautions to delay time of vehicles in the traffic. Proposed work in [18] uses the IoT concept to control the traffic congestion as vehicles and traffic lights can be able to communicate directly with the help of IoT. In the proposed work in [19], artificial intelligence and machine learning is used to develop an intelligent traffic system. The approach in [20] estimates the waiting duration based on the number of vehicles which detected using video processing beside statistical methods such as cluster analysis, multiple regression analysis, and factor analysis. The proposed system in [21] has combined video surveillance and big data analytics algorithm to manage the traffic. Table 1 summarizes some of the most recent strategies in traffic control systems with their points of strength and weakness. Despite of their effectiveness, they do not achieve the superiority in all factors of performance. So, there is still a critical need for efficient traffic management strategy that combines superior traffic measuring and optimal timing techniques. Some of the works illustrated in table 1 are used for the comparison purpose through the experimental results in Section 4.

Table 1 Recent efforts in traffic control systems

Strategies	**Year**	**Contribution**	**Benefits**	**Shortcomings**
Intelligent traffic light under fog Computing platform in data control of real-time traffic flow [15].	2021	Use Q learning algorithm utilizing fog computing to propose a control method of Intelligent traffic light (ITL).	Efficiency, good performance.	Emergency vehicles have not given priority.
Multi-agent system for intelligent urban traffic management using wireless sensor networks data [16].	2022	Recommends k-nearest neighbor and random tree classification models forecast the traffic flow with maximum accuracy.	Improving the communication between agents.	Can't deal with scenarios like ambulances passing by, VIP visits, and other crises.
Traffic Control Prediction Design Based on Fuzzy Logic and Lyapunov Approaches to Improve the	2021	Fuzzy model of an urban traffic network was implemented for a single intersection.	Minimum energy consumption, reduce queue length.	Fixing features can take a long time and be ineffective.

Performance of Road Intersection [17].				
IoT-Based Smart Traffic Light System for Smart Cities [18].	2021	Proposed a smart system which connect between the vehicles and the traffic light through the cloud computing.	Reduce complexity.	Changes in lanes are not factored.
Intelligent traffic signal control system using machine learning techniques [19].	2021	Introduces an intelligent system that uses machine learning and reinforcement learning to control the traffic.	Real-time prediction.	No connection between the drivers of vehicles and the system.
IoT Based Road Traffic Control System for Bangladesh [20].	2021	Develop an IoT based advance traffic control system.	Can handle emergency traffic situations.	Time complexity
Efficient Strategies to Manage Road Traffic Using Big Data Analytics [21].	2022	Introduces framework traffic event detection system.	managing big data efficiently.	No adaptive traffic signal management.
Intelligent Traffic Management System Based on the Internet of Vehicles [22]	2021	In this work, vehicles communicate with the Intelligent Signals wirelessly to achieve their services and provide the ideal traffic flow.	Gives priority for the emergency vehicles.	Does not use Ai to detect the traffic data.
A framework for dynamic smart traffic light management system [23]	2021	Determines priority based on the level of the traffic congestion, assessed by processing of images taken by the digital cameras.	Use digital cameras to detect the traffic data.	Low throughput.

3. The Proposed Smart Traffic Strategy (STS)

The ultrasonic sensors and digital cameras would detect the traffic density and communicate to Arduino, which is a part of the smart traffic light that is responsible for acquiring signals from sensors on the roads, which in turn will communicate with the fog-computing node. Fog computing node responsible for calculating the optimal waiting time for the traffic light accordingly. Therefore, as a result, the collected data will help the system in monitoring the roads and calculate the green light time of each road based on the traffic density. There are three consecutive tiers in STS as shown in figure 2. The first tier includes a road occupancy measurement by the smart traffic light based on data collected from ultrasonic sensors and digital cameras, as well as each vehicle's information. Vehicle's information is registered through the STS android application. Second tier is sending the data to the fog computing node server. Fog computing server predict the optimal waiting time based on the collected data, taking emergency situations into consideration. Figure 4 indicates how STS manage the urgent cases and give priority to the emergency vehicles.

If the emergency flag f_1 equals one this means that, the lane has an emergency vehicle. This appears in the output priority, as Y will equal zero if both F_0 and F_1 equal one. Which give the priority of green light to this lane. The index i in the Y_i refers to the lane number. Third tier is applying the calculated optimal waiting time to the traffic lights in each lane and reduce the traffic congestion. Servomotors which connected to barrier have been added in each lane to lock its entrance if it has red or yellow light, which adds more control and support the decision of the traffic lights as presented in figure 3.

Figure 3: STS prototype components

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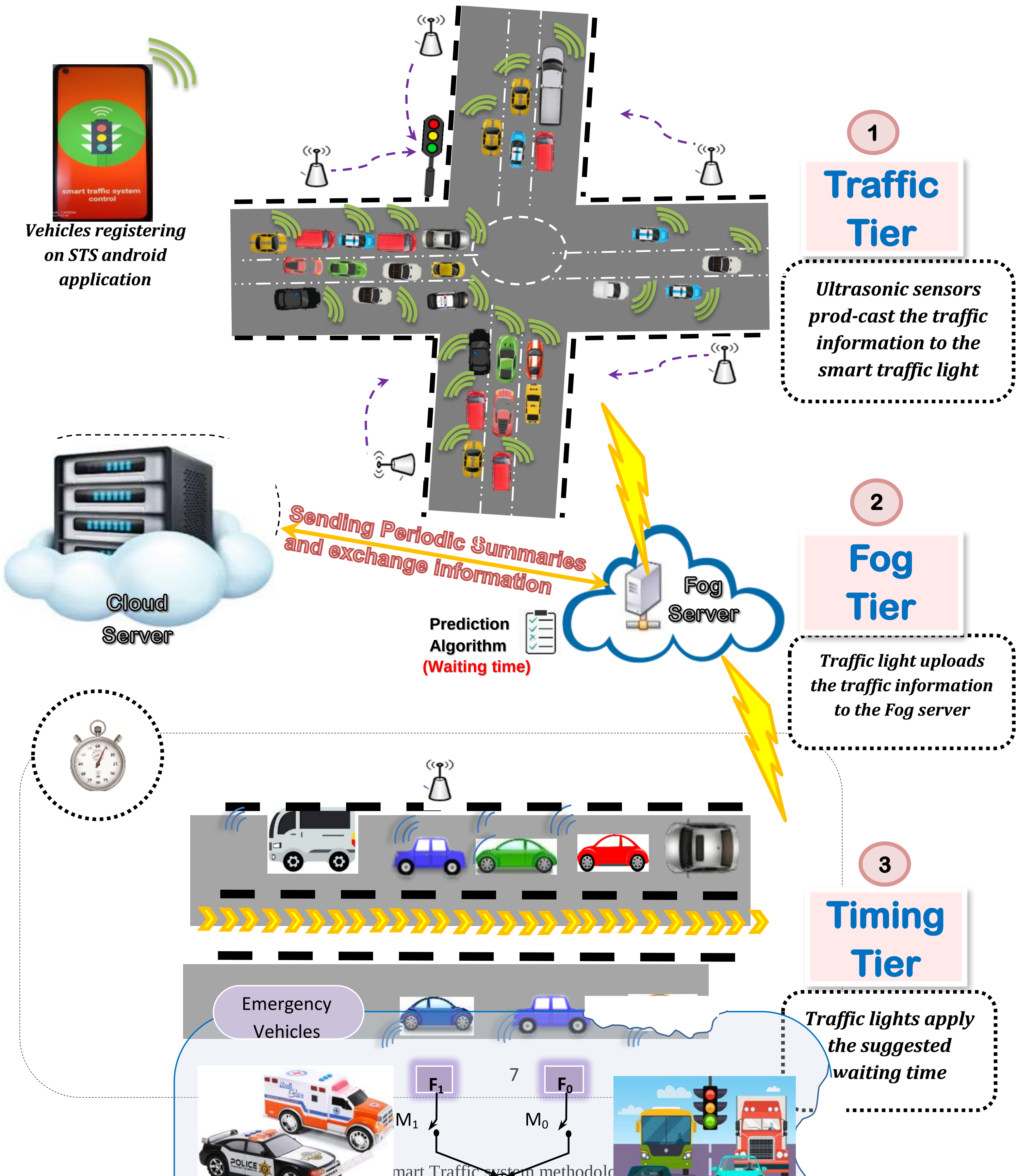

mart Traffic system methodolo

3.1. Vehicle registration procedure

Vehicle registration process help to provide the system with traffic volume. STS application not only serve the traffic management system but also help registered users. As STS application help to get an updated traffic map, thus the user can choose the least crowded route at this time. As shown in figure (5-a), the vehicle's registration process include 6 inputs. The user name is entered beside the personal ID, which give the ability to get this vehicle if there are violations, and breaks to the traffic laws. Also the user's personal phone number and email are provided to get notifications and to be in a good contact with the system. A password is also needed to get an accurate sign up process. Figure (5-b) and (5-c) show the user location on the map and the live traffic consequently.

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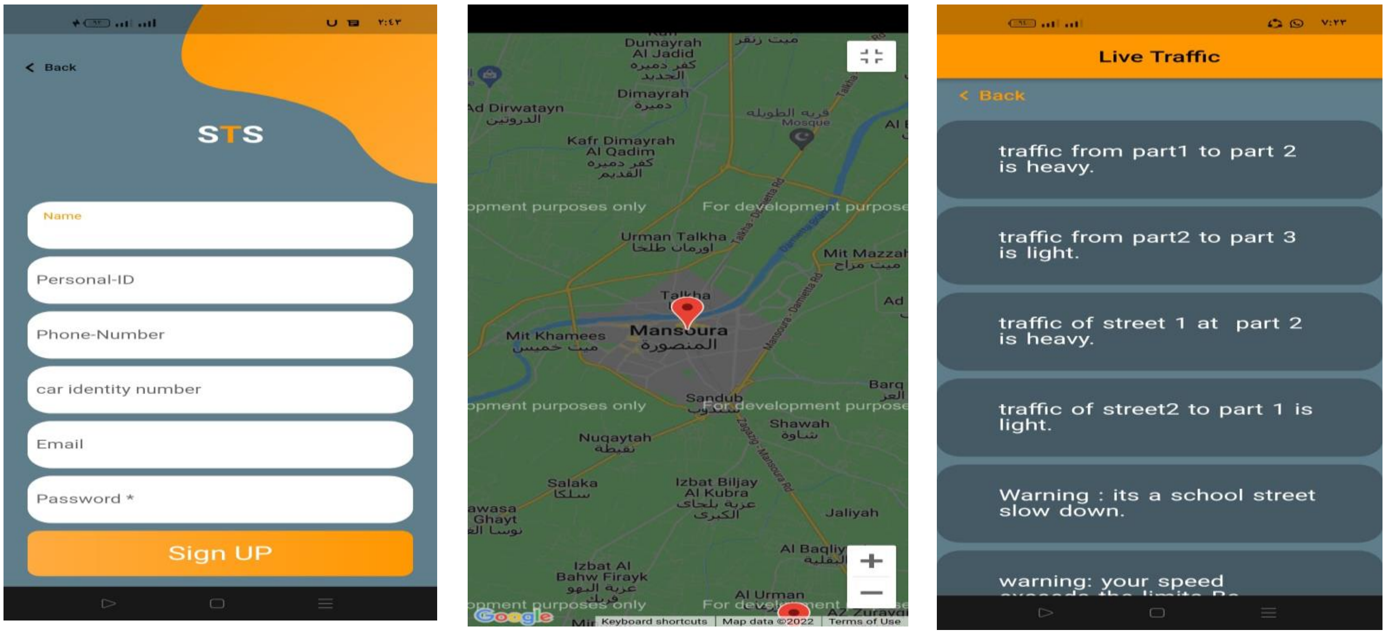

(a) Sign up screen (b) STS map (c) STS live traffic

Figure 5: (a) STS registration screen, (b) STS map, and (c) STS live traffic.

3.2. Mathematical Model

In this section mathematic equations are discussed which used to evaluate the green time to each lane. As a real time application, authors use light equations to ensure the shortest processing time. At first, the total number of vehicles calculated by eqn. (1). While the time for one cycle is given by eqn. (2). Where N_{tv} is the total number of vehicles at all lanes while N_v is the number of vehicles in each lane, T_c is the total amount of time for one complete cycle of the traffic lights. While α is the time needed for any vehicle to cross the traffic light, in the simulation results α used by 2.5 sec. Now we need to make the traffic light more reliable to calculate the green time at particular lane by Compensation eqn. (3) and (4). Where R in eqn. (3) is the ratio between the total number of vehicles inside the lanes and the number of vehicles in particular lane. The green time at a particular lane indicated by T_L which given by eqn. (4).

$$N_{tv} = \sum_{v=1}^{4} N_v \qquad (1)$$

$$T_c = \alpha * N_{tv} \qquad (2)$$

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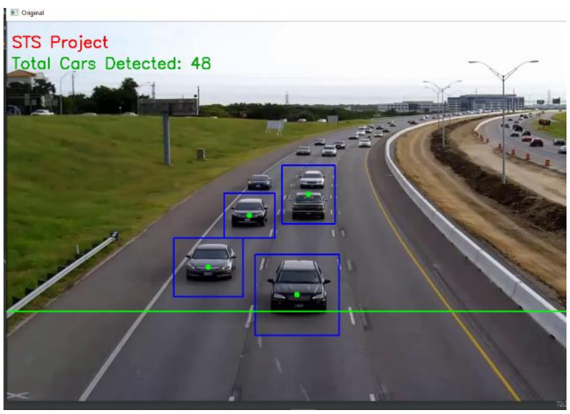
$$R = \frac{N_v}{N_{tv}} \qquad (3)$$

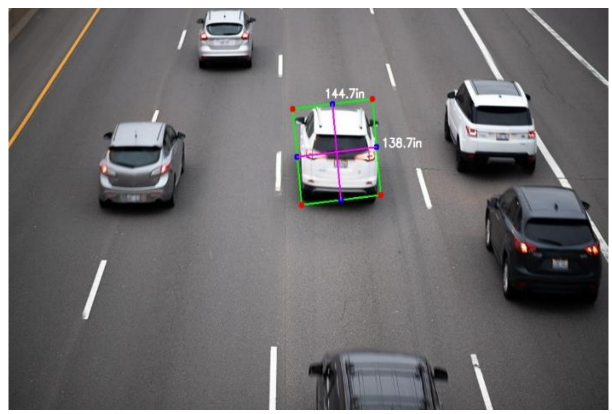
$$TL = R * Tc \qquad (4)$$

3.3. Detecting the number and size of vehicles

Beside the ultrasound results for detecting the number of vehicles, STS also used image-processing algorithm to detect the number and size of vehicles. A Live video showing the varied density of vehicles on the road is processed and get the desired data about the number and size of the vehicles. Installed digital cameras on the lanes feed the system with a live traffic video. At first, canny filter has been used to detect the borders of each vehicle in the live video as shown in figure (6-a). Then the number of vehicles detected using a counting function in each frame of the processed video. Also vehicle dimensions detected as shown in figure (6-b).



(a): Vehicle detection



(b): Dimensions of the vehicle

Figure 6: Detecting the number and size of vehicles

There are a massive number of edge detection algorithms that have been used in edge detection. These algorithms divided into two types. First type depending on Gradient (difference) based operator, which relies on detecting the edges by looking for the maximum and the minimum in the first derivative of the image. Canny Operator, Roberts Operator, Prewitt Operator, Sobel Operator, and others are examples of these operators. Second type is Laplacian (zero-crossing) based operators. Zero-crossing method detects for zero crossings in the second derivative of the image to find the edges. The two methods are compared in table 2. Canny edge operator uses a multi-stage approach to determine the edges of objects in a given image [24].

4. Simulation setup and Results

In this section, the proposed Smart Traffic System (STS) is assessed and compared with some of the recent traffic management techniques. Simulation is set up assuming that there are 4 lanes intersection road. Each lane of this intersection has 1 fog node which collects information from ultrasound sensors, the installed

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digital cameras, and the STS android application. The simulation has been executed in two stages, first stage belongs to fog in which both the size and number of vehicles have been detected and simulated using python

to increase the accuracy of the collected data from ultrasound sensors and beside the registered vehicles on STS android application. Second stage is predicting the optimal waiting time using STS algorithm. Finally, Python and pygame displayer, which presented in figure 7 are used to test the developed algorithm and compare it with some recent traffic management systems.

Operators	Sensitivity	Operation	Advantage	Disadvantage
Sobel Operator	Medium	Maximum of edges are identified with respect to perpendicular angle	Simplicity finding of smooth edge	Inaccurate average results with respire to complex images.
Prewitt Operator		Provide a better performance on horizontal and vertical edges in the images		
Kirsch Edge Detection		The maximum effective edges are found in each mask.		
LoG	Good	Considers the double edge images.	Check the pixels in wider area and accordingly find the exact edges.	Few edges cannot be detected.
Robert's cross operator		Continuous edges can be detected using raw images.		
Robinson Edge Detection		Find the 2 – D spatial gradient measurement on an image.		
Canny Optimal Edge Detection	High	Used to eliminate the noise and to find the effective edges.	Finding the error rate is high. Better detection and remove streaking problem. Adaptive in nature and good localization.	False Zero crossing.

Table 2: Comparison of various edge detection techniques

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Figure 7: Traffic Simulation

4.1.Throughput

Throughput of the system defined as the number of vehicles that cross the intersection per second. Simulation comparison have been applied among the proposed STS and other recent traffic light management scenarios,

IoV [22] is used. IoV assumed that the maximum distance measured from the intersection stop line is 400 m, the vehicles enters the lane every 2.5 s, the size of vehicle is 4.5 m, and the gap between vehicles is 0.5 m. Therefore, the maximum number of vehicles in any road is 80 vehicles for one lane and having two lanes, the maximum number of vehicles is going to be 160 vehicles. STL [23] use simple mathematical calculations to calculate the total time for a cycle. STL assumed that the traffic light is open for 30 s with four roads intersection. Suppose two vehicles come in each 15 s and 3 vehicles exit in each 6 s at green light for each road, the total time for a cycle equals (30+30+30+30=120 s). Average number of vehicles that arrive in a cycle = (90/15)*2 = 12 .Number of vehicles that would exit during 30 s greenlight period = (30/6)*3 = 15 vehicles. The only modification at this system is adding an extra time of 16 s to the green traffic light duration to avoid congestion. Throughput has been measured for each system by substitution in the equations and algorithm of each system. The results of each system identify the variation between the time and the number of crossing vehicles.

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Figure 8 shows the number of vehicles that pass the road intersection per second using the proposed STS algorithm which achieve the benchmark values of the throughput at [4]. As shown in figure 8, IoV and STL have less throughput than STS. STS accuracy has been proven as the number of crossing vehicles is greater than the waiting vehicles, which identified in the throughput.

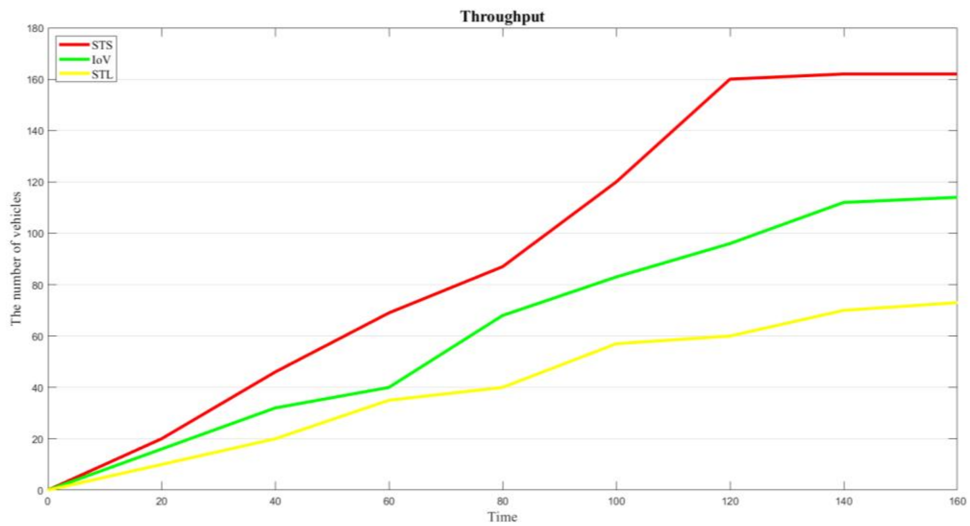

Figure 8: Throughput of traffic intersection

4.2.Total average delay

The delay is challenging and sensitive task in the traffic management systems. Which requires dynamic and rapid network and light algorithms. However existing several strategies and techniques to solve the traffic problems but a few of them study the total average delay guarantees. STS methodology claimed to achieve delay guarantees. Using fog computing allow STS to receive the real-time stream data and predict the optimal waiting time. Fog based algorithm helps to get rid of wasting time in data gathering and sending to far centered servers to make decisions faster. Red traffic time is predefined for vehicles in each lane to cross the intersection. As presented in figure 9 the delay time of STS has acceptable values in case of this large number of vehicles in the simulation process which refers to the correct choice of the yellow light time (5 sec.) and the mobility of the system. The total delay in STS is 10% less than the required delay in IoV and 40% less than STL. Therefore, proposed algorithm (STS) claimed a better performance against the IoV and STL, in terms of its ability to decrease the average delay per vehicle.

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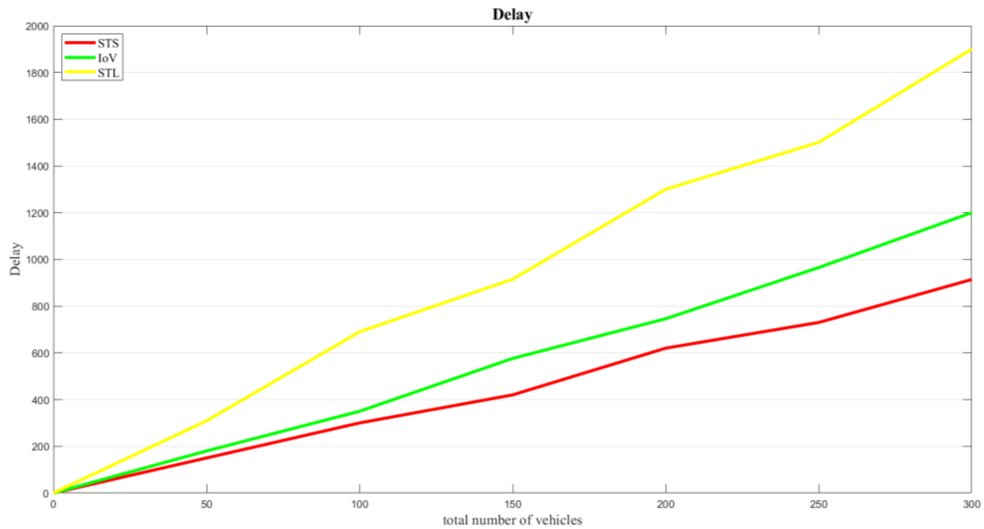

Figure 9: The total average delay

The results reveal that the proposed smart traffic system accurately calculates the optimal waiting time for each lane, which prolongs the time of green light properly to certain lane when the number of vehicles increases.

5. Conclusion and future work

STS is a traffic light management system which support smart cities based on fog computing. Ai used for detecting the number and the size of vehicles to reduce the waiting time in each lane and reduce the air pollution and consumption of fuel for vehicles. STS employs simple hardware prototype beside using simulators infrastructure to provide an efficient and intelligent traffic control system for local intersections. STS supports any number of phases and fully parameterized, which, can increase the transportation efficiency and performance by enhancing the throughput and decreasing the average delay of vehicles. Consequently limits the air pollution and fuel consumption usage. Simulation results ensure that STS enhance the throughput and decrease the average delay about 40 % compared to existing algorithms which means that STS could be a candidate for the traffic control system in the smart cities. Cost and complicity are the biggest challenge in the traffic management systems, which are considered in STS. To expand the currently proposed algorithm, future work can be extended in using the AI in the optimization process for the traffic control process using the distance between each vehicle and the traffic light unit and considering the speed of vehicles. After time of STS operating, a huge data will be collected about traffic congestions and states which can be mined or analyzed by suitable algorithms to get future planning and enhanced decisions.

6. Compliance with Ethical Standards

This article does not contain any studies with human participants or animals performed by any of the authors.

7. Data Availability

All the support source code of the software and the simulations of this study are available from the corresponding author upon request.

8. Declarations

Authors declare that they have no conflicts of interest.

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