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An IoT based Traffic Control System using Spatio-Temporal Shape Process for Density Estimation

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ABSTRACT- In response to the escalating challenges posed by urban congestion and road accidents, this paper addresses the imperative for advanced traffic control systems in smart cities. However, there is limited research work available in the literature to develop this traffic management system due to unpredictable traffic flow occurring on the road. To overcome this shortcoming in the traffic control system, this paper proposed a novel vehicle density estimation method that considers group of vehicles, availability and applicability of IoT in smart cities provide an efficient medium to handle public safety by using condition-based intensity function that will be a medium to cope with traffic challenges and thus build an intelligent traffic control system.

Keywords: IoT Traffic Management System, Density Estimation, Sensors, Traffic Control, Accident Detection.

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1. INTRODUCTION

Due to growth in population and incomes of every individual led to rise in ownership of vehicles and thus occurrence of vehicles in the roads. Therefore, traffic congestion is inevitable one in recent years. Also, road accidents are increasing every passing year and thus accidents people get injuries, infirmities, and die [1-2]. Not only vehicles are the reason for accidents and the road accidents are caused by the following reasons: human or vehicle suddenly crossing on the road, drunken driving, the inaccurate road infrastructure, driver with high speed, driver sleep or fatigue, etc. The patient suffers in the hospital or ambulance due to delays in medical emergencies caused by the heavy traffic [3-4].

Internet of Things (IoT) is the current technology which can provide the internet to any kind of device to monitor or control the device everywhere. In recent days, physical devices with internetworking gives more advantages to life and several IoT applications are available in reality namely, health care, water supply, traffic management, hospitality, agriculture, etc. Also, the several research works are currently concentrated on self-driving cars. To develop the self-driving car, the transport environment needs to be re-design the transport organization. This development of all the parts of vehicles can be interconnected with internetworked with similar embedded traffic scenarios. A traditional traffic system includes four lanes, each lane having a signal with a predefined fixed timer on each end which operates consecutively. However, the traditional traffic system cannot detect the density of traffic on each lane and this problem leads to waste of time even if the lane is empty. Also, this kind of traffic system cannot control the vehicles from blocking people crossing in the road, it cannot check the density of vehicles on each lane, it cannot check whether the traffic condition of a vehicle route is right [5-7]. This paper presents a novel approach, termed as the Spatio-Temporal Shape Process Density Estimation (STSPDE) method, aimed at enhancing the accuracy and efficacy of IoT-based Traffic Control Systems (TCS) by precisely estimating vehicle density in traffic surveillance videos. The key contributions of this work are outlined as follows:

1. The proposed STSPDE methodology encompasses four distinct phases, namely IoT data collection, vehicle detection, traffic density estimation, and traffic control system implementation.

2. The STSPDE method introduces an innovative approach to identify vehicles region within traffic surveillance videos.

3. Through the application of morphological operators and connected components algorithms, the methodology accurately identifies and groups vehicles within the surveillance footage, enabling precise analysis of traffic density.

4. The integration of IoT technology enhances the capabilities of the traffic control system by providing actionable insights into traffic patterns and dynamics.

2. RELATED WORK

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This section discusses the research work on IoT based traffic systems for detecting accidents and controlling traffic. This section also explained various types of sensors and their purposes of the IoT based system.

IoT based Accident Detection System: an accident detection system [8] through an android application using accelerometer by applying methods namely dynamic time warping and hidden markov models. The system can send the messages where accident location and severity of accidents are sent to police and family members. Bhatti et al. [9] developed a smart phone which consists of several built-in sensors namely speed, pressure, sound, location, and g-force with low cost and portable solution, it can send the reports about an accident to the nearest hospital. Dar et al. [13] developed a low-cost smart phone system which is based on fog computing approach. This system uses an android application to detect an accident by taking inputs through smartphone sensors. This system can be informed to nearby hospitals through GPS if an accident is detected. Fernandes et al. [14] have modelled android applications. Road hazard warnings problem is raised by this model. In order to improve the internet connection to nearby vehicles for getting required messages, ad-hoc network can be used. These approaches can help vehicles which carry out reporting accidents. Rachedi and Badis [15] programmed a hybrid architecture that is based on the virtual backbone by selecting parked vehicles. Cellular communication links could be reduced by this architecture. Mekki et al. [16] analysed the problem about a vehicular cloud access which is designed as an evolutionary game using algorithms namely two vehicular cloud access and distributed Q-learning. The vehicle rollover events detection system is developed using accelerometer and gyroscope data [17-19]. Smolka et al. [20] developed a collision system based on smartphones using the sensors namely accelerometer, GPS, and magnetometer to reduce the false alarms.

IoT based Traffic Signals System: to handle traffic signals dynamically in real-time, an IoT based traffic monitoring system is developed [21] based on traffic density. This traffic monitoring system was developed using a set of ultrasonic sensors to detect vehicles and compute the vehicle density levels. Also, it consists of two modules where one module is used for vehicle monitoring and another module is used for analysing the priority vehicles management. In a similar way, a traffic monitoring system was developed for finding the road interaction using an ultrasonic sensor [22]. This system could be used in traffic signal lightings. Also, it can handle the wrong vehicle activities problems namely crossing the vehicles while red signals. The following sensors are used namely cameras and RFIDs for the data collection. Therefore, the application layer can control the traffic signal automatically using traffic density as well as providing a daily report about the traffic details through a web application. For estimating density of traffic congestion and updating the traffic signals, vehicle monitoring systems are used in reality [23]. Handling emergency vehicles namely police cars, ambulances, fire engines is very critical since the delay of every second suffers the public or patient. Therefore, the traffic monitoring system should provide the urgency of the services to the above said vehicles. The following research works concentrated on automatic scheduling procedures of emergency vehicles, this procedure can be worked by controlling and managing the traffic signals [24-25]. This procedure can help to improve the response time [26]. This system is mainly designed for highways.

To improve the traffic management system, this paper proposed a novel STSPDE method for estimating vehicle density to control the traffic signals.

3. THE PROPOSED STSPDE METHODOLOGY

The aim of the proposed STSPDE work is to develop the model to increase accuracy for IoT based Traffic Control System (TCS) by estimating the vehicle density in the traffic surveillance video. The proposed work consists of four phases such as IoT data collection, vehicles detection, traffic density estimation, and traffic control system. 3. 1 IoT Data Collection.

The traffic control system receives a traffic surveillance video as the input. Let *V* be the traffic video which consists of *N* frames where $f_i = f_1, f_2, ...f_N$ is the individual frame. Let D_{mn} be the 2-dimensional data matrix of f_i where *m* and *n* represent the row and column of the data matrix. The vehicles appearance is to be analysed on lane only, therefore, the Region of Interest is to be fixed while developing the TCS. Let *A*, *B*, *C*, and *D* are the four corners of ROI where horizontal *X* coordinates lies between *A* and *B* and vertical *Y* coordinates lie between *C* and *D*. In the similar way, the developer can make the number of ROI depending on the architecture of the traffic surveillance area.

3.1. Foreground Region Identification

The proposed work STSPDE takes the color frame sequence *N* as an input. In general, the RGB frame involves the loss of image information compared with grey scale image format since the RGB color is easily influenced by the light scattering or reflection. Therefore, RGB color frames have to be converted into gray scale images [27] using the *equation 1.*

$$P_{gray}=\frac{P_R+P_G+P_B}{3} \tag{1}$$

where P_R, P_G, and P_B are the red, green and blue color channels of RGB respectively. This P_{gray} *is* carried out by BM [28] to identify the foreground region. Let *K* be the reference frame. Each gray scale image P_{gray} is subtracted from *K*. It is denoted using the *equation 2*.

$$B_j=\left[f_{xy}\right]-\left[k_{xy}\right] \tag{2}$$

The f_{xy} and s_{xy} denote the x-axis and y-axis corresponding position pixels respectively.

Further, the resultant gray images are needed to convert into binary image due to binary image leads to decease the noise issues. The binary conversion is to be done by the *equation (3)*

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$$b(x,y)=\begin{cases} white\ pixel, |\ fg(x,y)-bg(x,y)\ |>\eta \\ black\ pixel, otherwise \end{cases} \quad (3)$$

where *b(x,y)*, *fg(x,y)*, and bg(x,y) are the individual pixels of binary, foreground, and background pixels in terms of *x*, *y* coordinate respectively. The η is the threshold value, it is applied on the difference of foreground and background pixels.

3.2 Vehicle Detection

Let G_j be the number of foreground frames which is extracted from the background of the frame sequence where $j = 1$ to *n*. Let *P* be the pixels where $P = \{x, y, t\}$ that are dented the number of pixels in both *X* and *Y* directions in *t* time. The *P* of G_j can express the size of the vehicles since the G_j may consist of one or more vehicles. To find the size of the foreground vehicles in the G_j and to find the relationship among the detected vehicles, the STSPDE is modelled. If G_j consists of more vehicles by the STSPDE, it may cause the problem to the public where it expressed the traffic congestion in the road.

To improve the foreground objects without any discontinuity, a morphological operator is used where erosion technique is applied to get the connectivity if the foreground objects break with multiple shapes and dilation technique is applied to avoid unwanted shadow on the foreground of the vehicles. Next, connected components algorithm [28-29] is applied where each foreground pixels connects with upper, top, left, and right pixels. Let e_k be the connected graph as a group of connected vehicles where $k = 1$ *to n*. The collection group of vehicles can be represented using the *equation 4*.

$$E = \{e_1, e_2, e_3, ...e_n\} \quad (4)$$

3.3 Traffic Density Estimation

In the traffic management system, measuring the traffic density is important to avoid unusual events such as accidents or vehicle collisions caused by traffic signals. Though the object density can be computed in several ways, still there are several challenges to extract object occupancy information estimation [30-32]. Due to inefficient vehicle density estimation by the vehicle's sensor, there is a possibility to send the wrong messages by updating the traffic signals. To overcome this challenge, this paper introduced a novel STSPDE method to estimate the vehicles density by the Surveillance Traffic Video (STV). Generally, video traffic monitoring is mainly used to compute the traffic density. Based on the traffic density ratio, the messages are updated to the traffic signals.

Also, newly entered vehicles and already entered vehicles are to be analysed to avoid duplicate vehicles identification. The information of newly and exited vehicles are to be taken into account for re-updating the vehicle density to the traffic signals. Also, the ratio of vehicle density determines whether vehicles or congested or not. This analysis is done only into the ROI.
Let e_k be a moving vehicle group. The Spatio-Temporal Shape Process (STSP) is found on the e_k to find homogeneity of each e_k. The STSP is drawn by its condition-based intensity function. Let δ^* *(t, x, y)* be the condition-based intensity function [33] where * emphasizes a function that is conditioned on the History (H_m) of the e_k in terms of intensity values where *m* is the time. It is explained in the *equation 5.*

$$\delta*\left(t^m, x^m, y^m\right)=\frac{\partial^3 I(M(t,x,y)H_m}{\partial t \partial x \partial y} \quad (5)$$

where $t^m = t, x^m = x, y^m = y$ and H_m expresses the history of the e_k before *m* time. *M(t, x, y)* is the counting function where the total number of intensity values of the e_k. The *M(t, x, y)* counts the number of pixels that should be less than horizontal *x*, vertical *y* and temporal coordinates *t* while *I[M]* be the expectation of the counting function. The variation between ek in the consecutive frame is found to check the certain ek whether newly entered or not. If the homogeneity variation is less than the threshold, the certain ek is already appeared vehicle and if the homogeneity variation is greather than the threshold the certain ek is taken as newly appeared vehicle. In case of ek homogeneity variation is less, the certain ek is removed from the E set to avoid the duplicate counting of ek.
Further, the Length (L) of the recognized e_k density can be computed by using the eqn. 6 in which x_1 and x_2 are the lowest and highest horizontal coordinates of length of e_k and y_1 and y_2 are the lowest and highest vertical coordinates length of e_k.

$$L=\sqrt{\left(e_{x2}-e_{x1}\right)^2+\left(e_{y2}+e_{y1}\right)^2} \quad (6)$$

The workflow of the STSPDE is explained in the *figure. 1*.

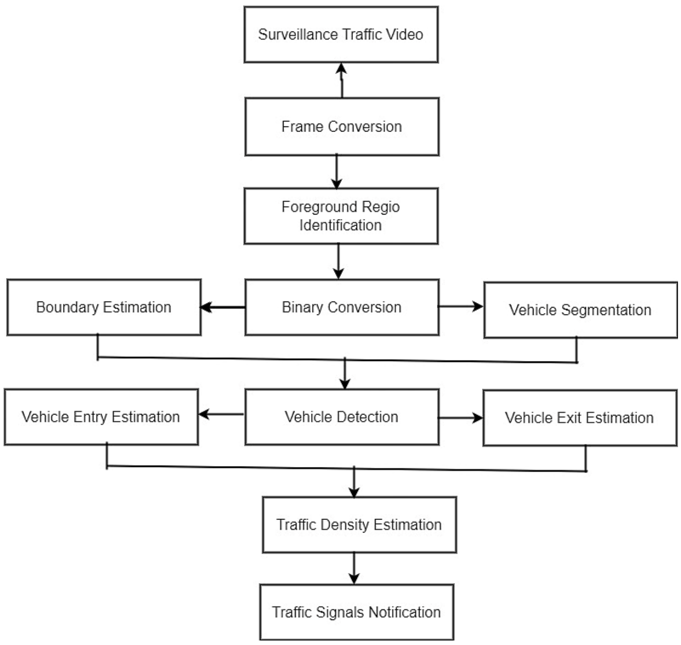

Figure 1. The workflow of the STSPDE

3.4 Traffic Signals Notification

The *L* is computed in three levels namely low, medium, and high congested vehicles. The traffic signals sensors have to be

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considered these three levels to give the notification. To accurate signal notification, threshold T is applied on the L, the value T lies between 0 to 1. In case of the system obtained the value 1, the e_k with high vehicle congestion. The signifies a very low congested if the system gets 0 value. Let Sensor A, B, C are the three traffic signal light sensors respectively. The T is applied on the sensor by following ways:

Low: (Sensor A = 0, Sensor B = 0, and Sensor C = 0)
Medium: (Sensor A = 1, Sensor B = 1, and Sensor C = 0)
High: (Sensor A = 1, Sensor B = 1, and Sensor C = 1)

A fixed time is fixed in the program code for each traffic level of estimating traffic density. The time is needed to analyse the vehicle appearance on the lane. It is estimated by using the frame rate where camera captures the scene with a frame rate of on an average of 25 frames per second and thus the frame rate can estimate displacement for each e_k for every frame. The model of the traffic management system is explained in the *figure 2*.

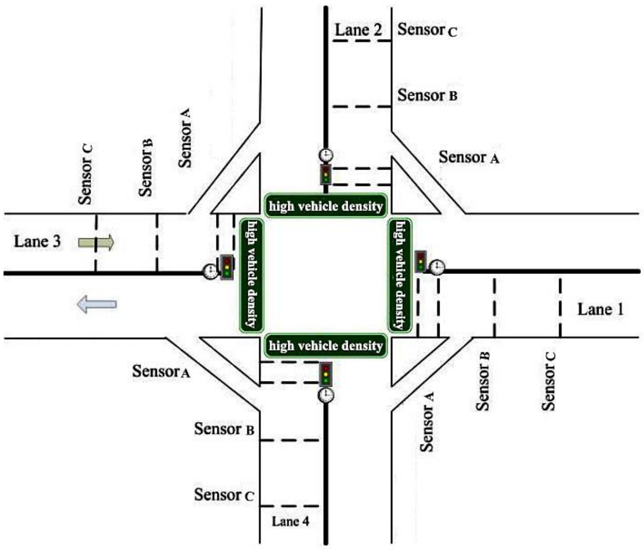

Figure. 2 The Traffic Management System Model

4. EXPERIMENTAL RESULTS

The proposed a STSPDE method to add vehicle density estimation to real-time vehicle sensors to accurately measure the vehicle density in the lane. The vehicle density measure is applied on the sensor by the following ways: the two nodes Q and R acted as client and U and V are the two nodes that acted as a server to estimate the vehicle density length from vehicle entry to vehicle exit on the ROI of a lane. This sensor node U acted as a server and R acted as a client while examining the lane occupancy measure. The sensor node R pass the messages to the lane side unit by WiFi connection and to the real-time data to the platform [34].

4.1 Performance Analysis

Lane occupancy estimation is an important measure to reveal the performance of the proposed work. The density estimation on lane occupancy measure is calculated using the *equation 7* by computing length of the density of vehicles that is given in *table 1* where road 1, road 2, road 3 are the three roads and their vehicle occupancy details for computing Relative Error.

$$Relative\,Error = \frac{(Estimated\,Value - Actual\,Value)}{Actual\,Value} \times 100 \qquad (7)$$

Table 1. Road Occupancy Evaluation

Road	Road Length	Actual Occupancy	Estimated Occupancy	Relative Error
road 1	300M	260M	274M	5.38%
road 2	250M	200M	208M	4.00%
road 3	400M	330M	348M	5.45%
Total	950M	790M	830M	5.06%

4.2 Comparative Analysis

In the comparative analysis, five similar existing models are taken to evaluate the effectiveness of the proposed method. The evaluation consists of number of monitoring, number of correct updating, number of signal control, administration updates, system scalability and the total score. The total score determines the system ability. *Table 2* shows the results of the proposed system gives better results and outperforms than the similar models.

Table 2. The System Evaluation

System	Real-Time Monitoring	Real-Time Update	Real-Time Signal Control	Administration Updates	System Scalability	Total Score (score/25)*100
[35]	5	5	0	0	5	60
[36]	5	3	5	0	5	72
[22]	5	3	5	0	5	72
[37]	5	3	5	3	3	76
[34]	5	5	0	5	5	80
Proposed System	5	5	0	5	5	80

5. CONCLUSION

This proposed work is an IoT based traffic control system model by using data collection, data processing, and storing traffic data for vehicle density calculation that consists of foreground estimation, vehicle detection, and vehicle density estimation, and traffic control system. To accurately estimate the vehicles density, this paper introduced a novel method STSPDE that uses spatio-temporal shape process technique, connected component algorithm, and morphological operation. Though the proposed method gives better accuracy in case of vehicle density estimation, vehicle sensors with density estimation do not address the Wi-Fi connection to communicate between devices. Also, the energy consumption of devices, their solution, and how to recharge them are needed to make the sensor-based vehicle congestion system. Therefore, this system can be extended to address the above said problems. This analysis can be used to estimate the road occupancy for single and multiple road services.

Author Contributions

Karthick Rajan is responsible for designing the framework, validating the results, and writing the article. T. Ganesh Kumar is responsible for critical review and K. Sampath Kumar is responsible for conceptualization.

Conflicts of Interest

The authors declare no conflict of interest.

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