Design of Real-Time Computer Vision System for Traffic Management in Smart Cities

Ph.D. Synopsis

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By

Trivedi Janakkumar Devendrabhai

Enrollment No: 159997111004 (E.C. Engineering)

Supervisor:

Dr. Mandalapu Sarada Devi,
Principal,
Ahmedabad Institute of Technology (AIT),
Ahmedabad, India.

Doctoral Progress Committee Members:

Dr. C. H. Vithalani
Professor
H.O.D.- E.C. Department
Government Engineering College
Rajkot, Gujarat, India.

Dr. K. R. Parmar
Ex-Professor,
Retired, H.O.D.-E.C. Department
Government Engineering College
Gandhinagar, Sector-28, Gujarat, India.

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1 Abstract

Intelligent Transportation System (ITS) is one of the vital parameter to build a smart city. The recent urbanization trends require lots of effort to control traffic congestions, pollution level, traveling time and parking management. In this work, different ITS applications, including smart parking systems, adaptive traffic light control system, vehicle classification, vehicle detection and counting, vehicle speed measurements (VSM), traffic sign detection & recognition, object detection and identification, are presented with the help of different methods.

Vehicle detection, counting and Vehicle Speed Measurements (VSM) are demonstrated using various morphology operations, Kalman filter, adaptive threshold, Euclidean distance and blob analysis with the help of Matlab. Computer vision-based VSM is implemented using Python and NVIDIA Jetson board to capture over speeding vehicles to reduce traffic accidents. The smart parking system is demonstrated using three parking prototype modules with circular hough transform (CHT) and edge detection techniques. Then real-time parking management system for mono and multi-cameras with different car parking positions is tested for Reliance Himalaya mall and Entertainment mall situated in Bhavnagar, Gujarat, using statistical block matching algorithm (SBMA). Then the car-parking mobile application is developed to get parking information. The advanced parking facility helps to reduce time and fuel.

The adaptive traffic light control system (ATLCS) for a four-way intersection point is implemented with the combination of SBMA and vehicle density value (VDV) using Graphical User Interface (GUI) and its prototype using the raspberry-pi board. ATLCS helps to lower traffic congestion problems at intersection points. In-vehicle classification module three different vehicles bike, cars, and a truck are classified using machine learning-based five different classifiers and deep learning-based convolution neural network (CNN) method to extract vehicular information using a digital image and video analysis. The classification helps to upgrade the automatic toll collection system and identify an emergency vehicle in traffic congestion.

The autonomous driving system (driverless vehicles) is the future of ITS. So, automatic traffic sign detection and recognition is significant for these vehicles. Traffic sign detection is done for the day and night videos using the Haar cascade method. Object detection and recognition of day-night time for Botad city, Gujarat using Yolo, Haar cascade method. Then the accuracy of object recognition is checked with our dataset and coco dataset.

2 Brief Description on the State-of-the-Art of the Research Topic

2.1 Motivation

The honorable prime minister of India has launched the "100 Smart Cities Mission" and Atal Mission for Rejuvenation and Urban Transformation (AMRUT), on 25^{th} June 2015 [a]. Top 50 smart city [b] in the world does not include a single city from India. Smart city application includes (1) smart transportation, (2) smart urban planning, (3) smart public health, (4) smart public security, (5) smart commerce [1]. To contributes towards smart city development in India, we decided to work on smart transportation.

The design of a computer vision system for traffic analysis is one of the essential parameters to build a smart city as the world is moving fast towards urbanization. The computer-vision based ITS is particularly essential due to its easy installation, fast response, ability to cover more extensive areas, and smooth operation and maintenance. Other methods, including the inductive loop, microwave detectors and sensors, suffer from severe drawbacks because they are expensive to install and to maintain. They are unable to detect slow or stationary vehicles.

Among numerous traffic surveillance methods, computer vision-based approaches have involved a great deal of attention and made significant involvement to practical applications of ITS such as vehicle detection and counting, vehicle speed measurements, vehicle classification, smart parking system, adaptive traffic light control system, traffic sign detection & recognition, object detection & identification, and automatic incident detection.

2.2 Literature Review

Traffic Management using image-video processing techniques is required including different ITS applications, with the help of an available surveillance system to build a smart city. Many researchers are contributed by developing different methodologies to get the best result from the available resources. Vehicle count using vehicle length and correlation computation and Vehicle classification using random forest method for small, medium, and large vehicles explained in [2].

Indoor parking facilities using radio frequency identification tag (RFID), high-sensitivity Global Navigation Satellite System (GNSS) receiver, ultra-wideband (UWB) transceiver demonstrated in [3]. The block matching approach consist of an efficient direction-oriented search algorithm explained for motion estimation discussed in [4]. Vision-based estimate for the number of vehicles passing through road-section over a continuous time interval described in [5]. Importance of road network density related to motor vehicle travel reviews in [6]. Motorcycle vehicle classification using K-Nearest neighbors and decision trees is explained in [7].

Frame differencing and blob analysis based vehicle detection and VSM using Euclidian Distance described in [8]. Object detection using a Haar Cascade method presented in [13]. You Only Look Once (YOLO) [12] give faster object detection and recognition with the computer vision. Performance evaluation measures, including recall, precision, and F1 parameters described in [14].

3 Definition of the Problem

This research aims to design a real-time computer vision system for the traffic management related applications, including smart parking system, vehicle detection and counting, vehicle speed measurements, adaptive traffic light control system, vehicle classification, traffic sign detection and recognition, object detection and recognition in the smart cities.

4 Objective and Scope of Work

The purpose of the present work is to investigate the potential role of the computer vision system in ITS for smart city development.

- To understand different methods of image-video processing for ITS.
- To develop prototype parking modules for real-time parking management.
- To develop an android based real-time car parking application.
- To develop the Adaptive traffic light control system for a four-way intersection.
- To validate classifiers for vehicle classification into bike, car, and a truck using CNN based deep-learning and machine learning methods with the help of feature extraction.
- To implement chosen popular optimization methods in the real-time video for vehicle detection and vehicle counting.
- To exploit the NVIDIA Jetson board's benefits for real-time vehicle speed measurements.
- To analyze traffic sign detection and recognition and on-road different object detection and recognition for the upcoming autonomous vehicle concept using Yolo and Haar cascade method for day and night time duration.
- To evaluate the performance of the above-developed methods by using standard benchmark performance parameters.

5 Original Contribution by the Thesis

In this work, the design and development of real-time traffic management using a computer vision system for a smart city are demonstrated and successfully tested. The original contributions of this research work is summarized as:

- The prototype smart parking system is implemented using a prototype for perpendicular and angular parking using circular Hough transform, Matlab and raspberry pi.
- A real-time parking management system is developed for Reliance Himalaya Mall and Entertainment Mall in Bhavnagar City, Gujarat, using the SBMA method for mono and multi-camera positions with different parking locations.
- The android car parking application is developed to check the availability of real-time parking space and to avail advanced parking facility.
- The computational time for the smart parking system is compared in each method.
- ATLCS for four-way intersection points using a combination of SBMA and VDV with GUI's help in Matlab and its prototype develop in raspberry pi.
- Vehicle classification into bike, car, and a truck done using different classifiers of the machine learning method and the CNN-based deep learning approach. The performance of each classifiers measures in terms of True Positive Rate (TPR), False Positive Rate (FPR), Positive Predicted Values (PPV), and False Discovery Rate (FDR) in terms of percentage. The deep learning approach based classification measured using the confusion matrix.
- The vehicle detection and counting using a combination of essential Morphology operation, adaptive threshold, Kalman filter, Blob analysis for a day, and night-time videos using Matlab, OpenCV, and python. The performance of the method is analyzed using recall, precision, and F1 parameters.
- VSM using a modified three-frame difference method and compares performance analysis using recall, precision, and F1 parameters. VSM implements in the NVIDIA Jetson board for faster and accurate response.
- For future work in the direction of the autonomous driving assistant system, fifteen different traffic signs are detected and recognized using Haar cascade for different day-time videos. The various object detection and recognition using the Yolo method for Botad day-night time video. Our dataset based detection and identification for different video results are compared with the predefined coco dataset.

6 Methodology of Research, Results/Comparisons

In this work, quantitative and qualitative research presents real-time traffic management applications using different methods for the performance evolution in this research work. During the first phase of the literature review, various research papers, journals, and other articles on different methods of image-video processing for traffic management control in smart city development are thoroughly studied. Many researchers had done work on the ITS application with the help of different ways including, Hough Transform (HT), Block Matching Algorithm (BMA), Absolute sum of frame difference method, CNN based deep-learning approach, Speeded Up Robust Future (SURF) and Scale-Invariant Features Transform (SIFT) based machine learning approach using Support Vector Machine (SVM) and K-Nearest Neighbours (KNN), Haar Cascade, You Only Look Once (YOLO), a combination of different morphology operation and Kalman Filter, Blob analysis and many more in the list. The Canny edge detection and simple block matching algorithms are tested for various real-world applications in the reported literature. Still, it has not explored to optimize a smart parking system.

Further, the combination of different morphology operations with Kalman filtering and Blob analysis is implemented for vehicle detection, counting, and VSM but only for a controlled environment. So in this work, the method is modified with the addition of adaptive threshold value and modified three-frame difference method to get an accurate result for day and night time duration. The research work on a different classifier for the machine learning method and CNN-based deep learning method presented. To use the benefits of this classifier, SURF features useful to compare to SIFT. Matlab simulates all this classification work. The importance of vehicle density value for traffic flow control explained by the researcher to reduce traffic congestion. In this work, the focus is to set ATLCS for four-way intersection points and compares the result with different conditions of fixed traffic light control system (FTLCS). Haar cascade is a well-known method in facial recognition, but in this work, traffic sign detection and identification performed using the Haar cascade method. The computer vision-based detection and recognition of different objects using Yolo attract many researchers for real-time applications. Finally, concluding remarks have been made, and the research substances are documented.

6.1 Smart Parking System

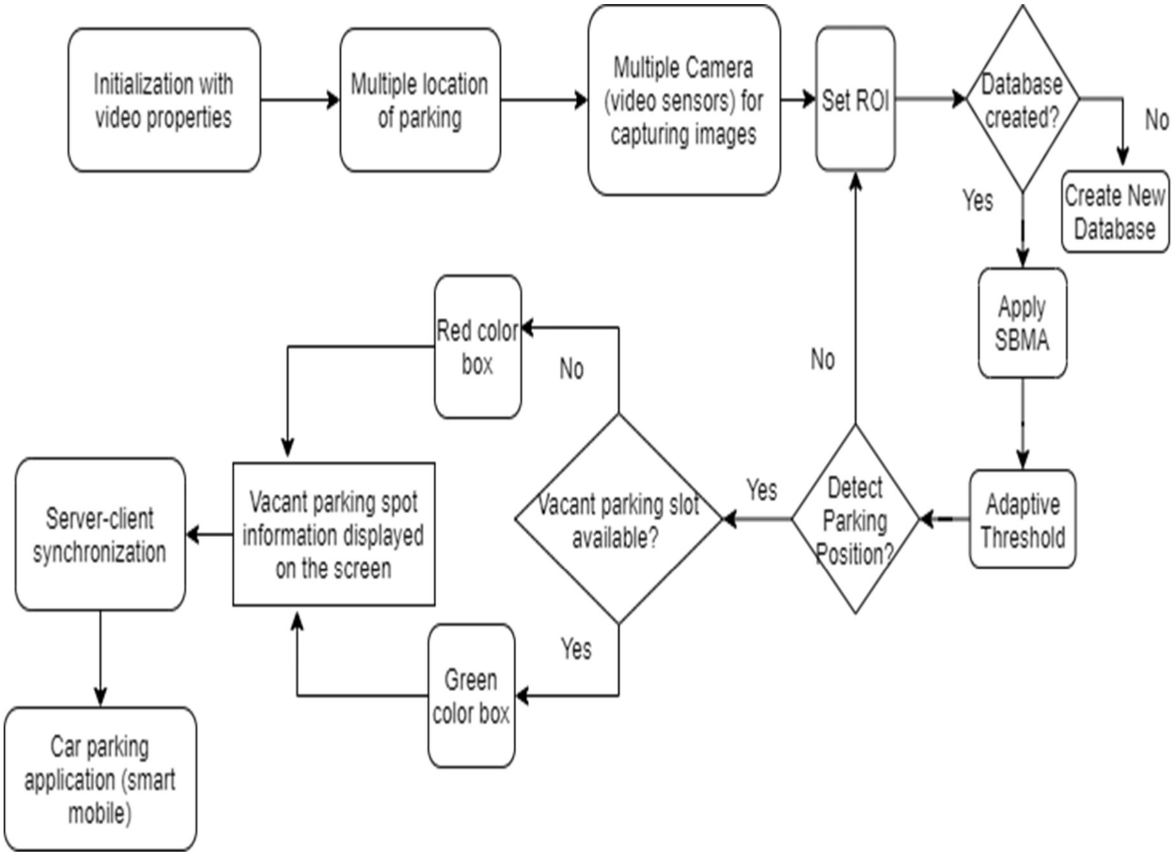

Figure 1: Flow diagram of SBMA for smart parking system.

The flowchart for the smart parking system is shown in figure (1). The computational time comparison of the SBMA method with different edge detection techniques shown in table 1. The performance of SBMA algorithms is evaluated based on recall, precision, and F1 parameters for 24 Hrs video duration of reliance Himalaya mall, Bhavnagar, Gujarat, as shown in table 2. Figure (2) represents the result of the parking condition for the Himalaya mall.

Table 1. The computational time for a different method

Sr. No.	**Method Name**	**Computational Time (Second)**
1	SBMA	~0.13 to 0.17
2	Canny	~0.39 to 0.58
3	Sobel	~0.17 to 0.20
4	Prewitt	~0.15 to 0.22
5	Roberts	~0.15 to 0.21

Table 2. Performance analysis for SBMA method, with Recall, Precision, and F1 Parameter, for car 1, car 2, car 3, and car 4.

C1, C2, C3, C4 respectively indicate car 1, car 2, car 3, car 4

18th June 2018, Camera-18, of Reliance Himalaya Mall, Bhavnagar, Gujarat, India.
Full day Video Analysis –with 24 hours/day. With Video Measurements parameters are- Frame rate-25, Resolution- 1280 x 720, RGB24 Format, .mp4 file format.

Sr. No.	Number of Frames	Duration of Video		Recall				Precision				F1			
		From (H:M:S)	To (H:M:S)	C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4
1*	19926	00:00:00	00:13:17	1	0.97	1	1	1	1	1	1	1	0.98	1	1
2*	100826	00:13:18	01:20:30	0.93	0.96	0.98	0.98	1	1	1	1	0.96	0.98	0.99	0.99
3	100828	01:20:31	02:27:43	1	1	1	1	1	1	1	1	1	1	1	1
4	100828	02:27:45	03:34:56	1	1	1	1	1	1	1	1	1	1	1	1
5	100828	03:34:59	04:42:11	0.99	1	1	1	1	1	1	1	1	1	1	1
6	100828	04:42:14	05:49:26	0.98	1	1	1	1	1	1	1	0.99	1	1	1
7	90776	05:49:28	06:49:58	0.67	0.73	1	1	1	1	1	1	0.80	0.84	1	1
8	10076	06:50:00	06:56:42	0.80	0.70	1	1	1	1	1	1	0.88	0.82	1	1
9	100826	06:56:43	08:03:55	0.57	0.46	1	1	1	1	1	1	0.72	0.63	1	1
10	100826	08:03:56	09:11:07	0.45	0.2	0.98	1	0.98	1	1	1	0.61	0.33	0.99	1
11	100826	09:11:08	10:18:20	0.40	0.16	1	1	0.98	1	1	1	0.57	0.27	1	1
12	100801	10:18:21	11:25:32	0.94	0.66	1	1	0.76	0.48	1	1	0.84	0.56	1	1
13	100776	11:25:33	12:32:46	1	1	1	1	0.60	0.05	1	1	0.75	0.10	1	1
14	100828	12:32:47	13:39:59	1	1	1	1	0.46	0.07	1	1	0.63	0.12	1	1
15	100828	13:40:00	14:47:13	0.98	1	1	1	0.72	0.15	1	1	0.83	0.26	1	1
16	100826	14:47:14	15:54:27	1	1	1	1	0.90	0.16	1	1	0.95	0.27	1	1
17	100826	15:54:28	17:01:39	1	0.96	1	1	0.94	0.50	1	1	0.97	0.66	1	1
18	100801	17:01:40	18:08:52	1	1	1	0.96	1	0.56	1	1	1	0.71	1	0.98
19	100826	18:08:53	19:16:05	0.97	0.97	1	0.90	0.90	0.95	1	1	0.93	0.96	1	0.95
20	100801	19:16:06	20:23:17	0.84	1	1	0.65	0.77	1	1	1	0.80	1	1	0.79
21	100801	20:23:18	21:30:28	1	1	1	0.48	0.94	1	1	0.97	0.97	1	1	0.64
22	100801	21:30:29	22:37:41	0.66	0.66	1	1	0.99	0.96	1	0.93	0.79	0.78	1	0.96
23	100826	22:37:42	23:44:54	0.99	0.99	1	1	1	1	1	1	1	1	1	1
24*	22650	23:44:55	00:00:00	1	1	1	1	1	1	1	1	1	1	1	1

*Here analysis of full day with 24 Hr. Video, where video number (1), (2), and (24) in a table with different time duration, but total time is 24 Hrs. 24 row doesn't indicate each row with a one-hour time duration.

Figure 2: 18th June 2018, Video Frame, from Reliance Himalaya Mall, Bhavnagar, represent where there are two cars parked, with Red color box and two parking available with Green box.

Android based car parking application developed to avail parking facility in advance. The car parking application is useful to know the exact parking location in the parking area. The registered users of car parking application can book the parking slot after recived simulation results from the multi-camera, multi-parking locations. The parking prototype is tested using combination of Raspberry-pi board, USB camera, toy cars, servo motors, LED. The parking prototype is tested using edge detection technique.

6.2 Adaptive traffic light control system

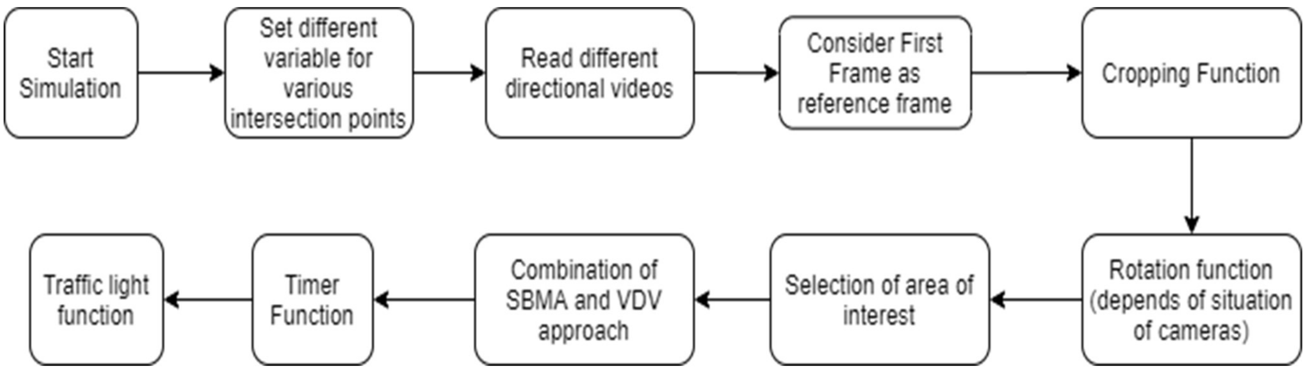

Figure 3: Flowchart of SBMA-VDV for ATLCS.

Table 3. Compare the timing diagram for a different traffic control system.				
Traffic Control System	Timing in second, stop time – 40, drive time – 15, wait time – 5.			
	Road A	Road B	Road C	Road D
Fixed Traffic Light Control System	15 + 5	40	40	40
	40	15 + 5	40	40
	40	40	15 + 5	40
	40	40	40	15 + 5
Fixed Traffic Light Control System (Without VDV, With Remaining time, full traffic)	15 + 5	40 – 5	40	40
	40	15 + 5	40 – 5	40
	40	40	15 + 5	40 – 5
	40 – 5	40	40	15 + 5
Fixed Traffic Light Control System (With VDV*, With Remaining time, full traffic)	15 + 5	30 – 5	45 – 5	60 – 5
	60 – 5	15 + 5	30 – 5	45 – 5
	45 – 5	60 – 5	15 + 5	30 – 5
	30 – 5	45 – 5	60 – 5	15 + 5
Adaptive (With VDV*, With Remaining time, controlled traffic)	10 + 5	25 – 5	40 – 5	55 – 5
	57 – 5	12 + 5	27 – 5	42 – 5
	38 – 5	53 – 5	8 + 5	23 – 5
	29 – 5	44 – 5	59 – 5	14 + 5
** As per changes in VDV values, complete cycle rotation of road A-B-C-D-A also varies. It always provides a higher number of cycle rotation compared to the standard traffic light control system.*				

VDV calculated using the mean of the selected Area of interest (AOI). First select, AOI for the selected roadside in the traffic signal. AOI calculates pixels' values information using matrix-vector operation for the selected region. Table 3 presents a comparison of ATLCS with different conditions of FTLCS. Figure (4) represents the adaptive traffic light control system at intersection points with VDV=0. Adaptive traffic light control system prototype module is tested using Raspberry-pi board. In that case USB camera, small toy cars, LEDs (Red, Green, Yellow) and display device (Computer Screen) are used.

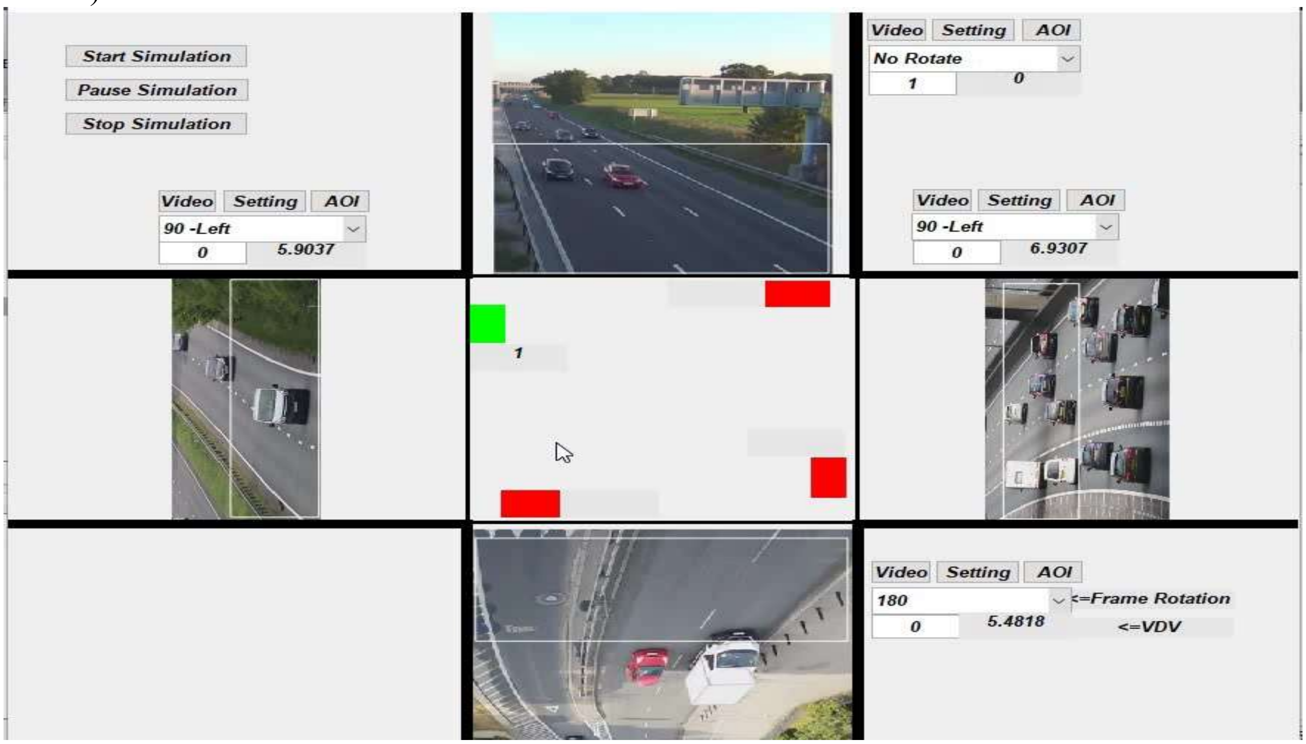

Figure 4: ATLCS with VDV=0

6.3 Vehicle classification

The vehicle classification is done with the help of convolution neural network based deep learning approach as well as classifiers based machine learning approach. The flow-diagram for vehicle classification is shown in figure (5). The vehicle classification for around 11k images into bike, car and truck with the help of SURF demonstrates using different classifiers.

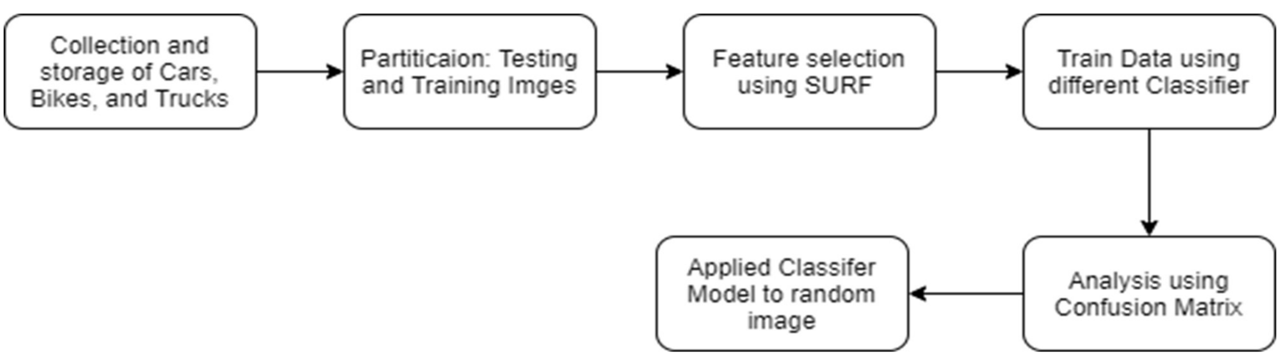

Figure 5: workflow for vehicle classification.

Table 4. Represents different classifier accuracy (in %) and prediction speed (in Obs/Sec).

Sr. No.	Classifier Name		Accuracy (%)	Prediction Speed (Obs/Sec)
1	Decision Trees	Fine Trees	68.6	2600
2		Medium Trees	66.3	2500
3		Coarse Tress	60.7	3100
4	Discriminant Analysis	Linear Discriminant	88.1	2400
5		Quadratic Discriminant	80.4	2000
6	Support Vector Machines (SVM)	Linear SVM	89	2100
7		Quadratic SVM	90	790
8		Cubic SVM	90.3	660
9		Fine Gaussian SVM	43.7	250
10		Medium Gaussian SVM	90.8	530
11		Coarse Gaussian SVM	88.5	550
12	K-Nearest Neighbour Classifier (N.N.)	Fine KNN	77.7	220
13		Medium KNN	80.9	260
14		Coarse KNN	81.1	260
15		Cosine KNN	81.7	240
16		Cubic KNN	79.8	10
17		Weighted KNN	82.3	270
18	Ensemble Classifier	Boosted Trees	78.1	1300
19		Bagged Trees	83.3	1100
20		Subspace Discriminant	88.4	630
21		Subspace KNN	82.6	20
22		RUSBoosted Trees	65.6	1500

Table 5. Vehicle classification of the Bike (B), Car (C), Truck (T) using Support Vector Machines (SVM) classifier, with TPR, FPR, PPV, and FDR in terms of percentage.

	Linear SVM					Quadratic SVM					Cubic SVM				
	B	C	T	TPR (%)	FPR (%)	B	C	T	TPR (%)	FPR (%)	B	C	T	TPR (%)	FPR (%)
B	1471	109	20	92	8	1489	96	15	93	7	1496	85	19	94	6
C	77	1376	147	86	14	75	1382	143	86	14	75	1386	139	87	13
T	22	151	1427	89	11	15	135	1450	91	9	14	136	1450	91	9
PPV(%)	94	84	90			94	86	90			94	86	90		
FDR(%)	6	16	10			6	14	10			6	14	10		
	Fine Gaussian SVM					Medium Gaussian SVM					Coarse Gaussian SVM				
	B	C	T	TPR (%)	FPR (%)	B	C	T	TPR (%)	FPR (%)	B	C	T	TPR (%)	FPR (%)
B	209	1391	0	13	87	1488	95	17	93	7	1467	114	19	92	8
C	0	1600	0	100	0	57	1434	109	90	10	79	1376	145	86	14
T	0	1313	287	18	82	17	147	1436	90	10	33	163	1404	88	12
PPV(%)	100	37	100			95	86	92			93	83	90		
FDR(%)	0	63	0			5	14	8			7	17	10		

Table 4 represents different classifier accuracy (%) with its prediction speed (Obs/sec). Table 5 shows vehicle classification into bike, car and a truck using support vector machine classifier with TPR, FPR, PPV, and FDR in terms of percentage. Highest accuracy in the case of Medium Gaussian SVM classifiers.

6.4 Vehicle detection and counting

A flow diagram of vehicle detection and counting shows in figure (6). Vehicle detection and counting results for different available [c] day-night videos using basic morphology operation are shown in table 6. When applying erosion and dilation operation together, the number of vehicle counting matches the approximate range of vehicles.

Table 6. Vehicle detection-counting for a different day/night videos.

Sr. No.	Traffic video with a frame rate	Morphology Effect	No. of Vehicle counted	Approx. Range of vehicle.
1	Chennai Traffic Video [c] -30	With Erosion and Dilation	10	~7-15
		Wit Dilation, Without Erosion	15	
		With Erosion, Without Dilation	11	
		Without Dilation and Erosion	18	
2	Ahmedabad Traffic Video [c]-24	With Erosion and Dilation	13	~8-13
		Wit Dilation, Without Erosion	22	
		With Erosion, Without Dilation	17	
		Without Dilation and Erosion	20	
3	Bangalore traffic video [c] -30	With Erosion and Dilation	65	~52-65
		Wit Dilation, Without Erosion	36	
		With Erosion, Without Dilation	29	
		Without Dilation and Erosion	65	
4	Mumbai traffic Video [c]-25	With Erosion and Dilation	143	~137-160
		Wit Dilation, Without Erosion	117	
		With Erosion, Without Dilation	211	
		Without Dilation and Erosion	173	
5	Night traffic Video [c]-30	With Erosion and Dilation	12	~12
		Wit Dilation, Without Erosion	9	
		With Erosion, Without Dilation	0	
		Without Dilation and Erosion	10	

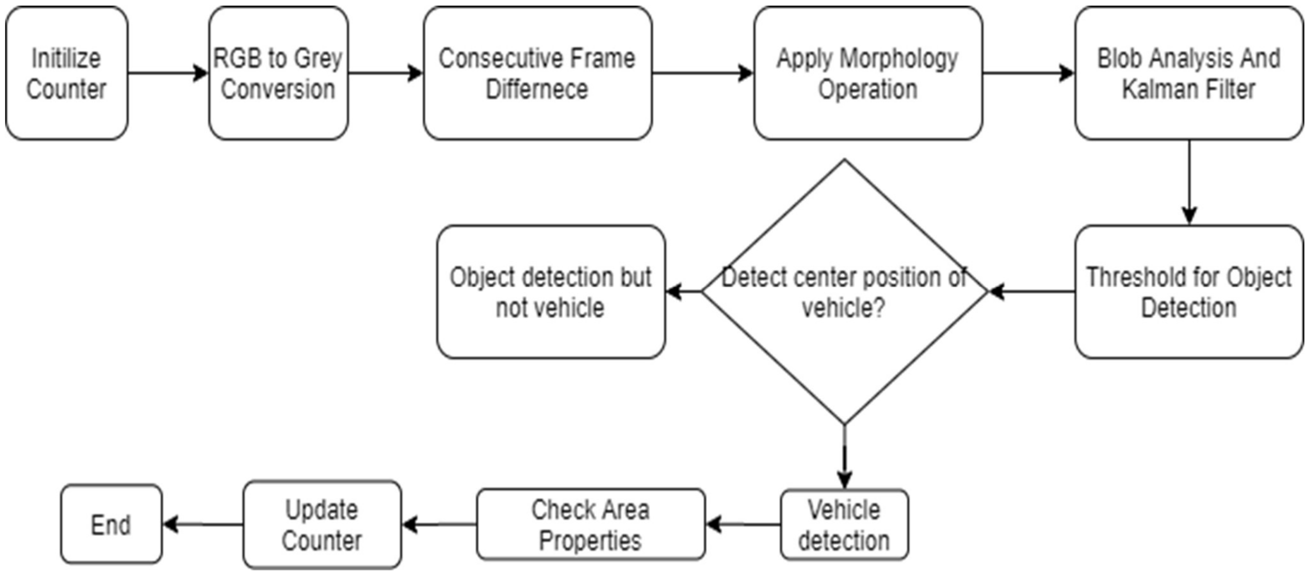

Figure 6: Flowchart of vehicle detection and counting.

6.5 Vehicle speed measurements

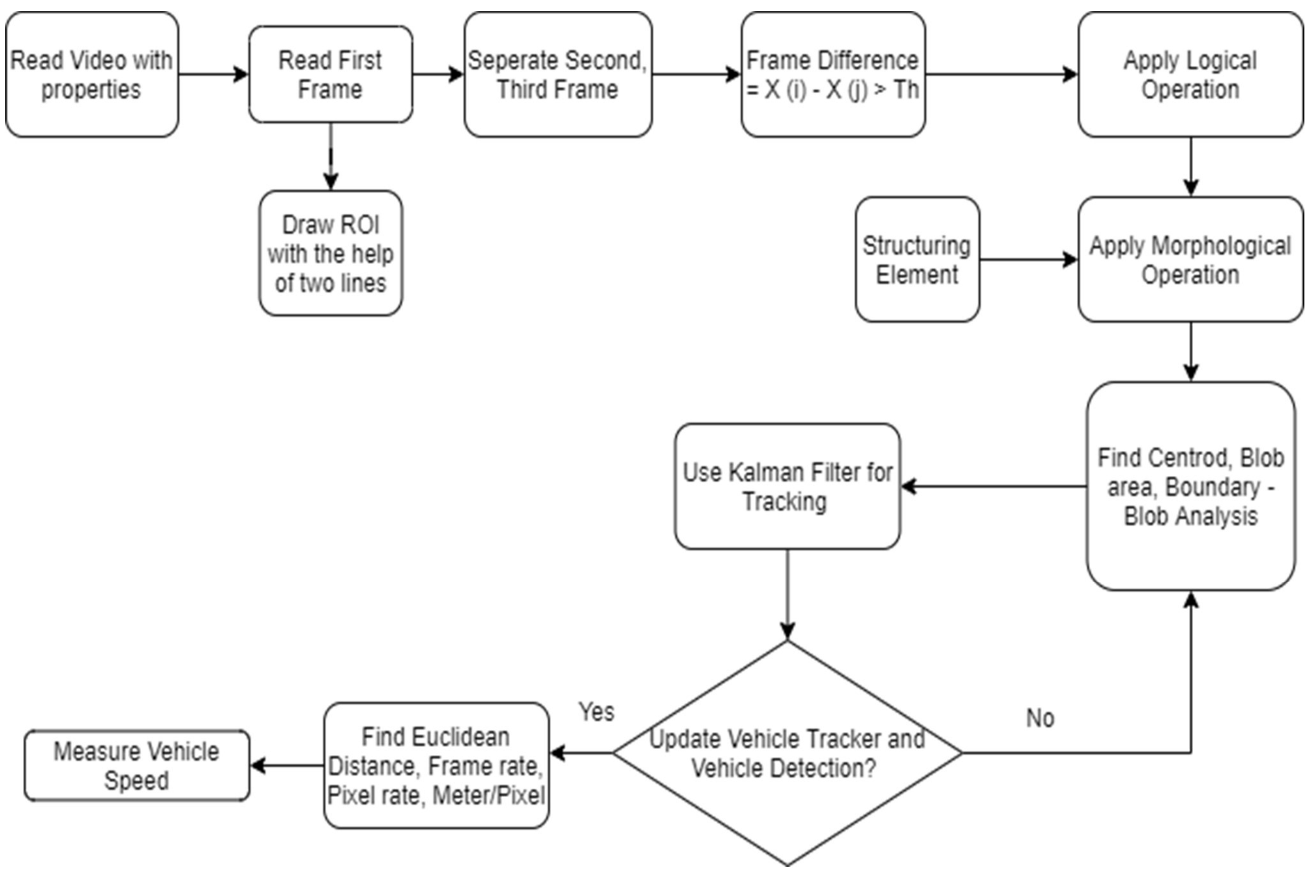

Figure 7: Flowchart for VSM.

VSM workflow is shown in figure (7). From Table 7, it observes that the proposed method for VSM gets higher recall and F1 parameters values. Figure (8) shows the result of VSM using the NVIDIA Jetson Board for Botad City, Gujarat. Vehicle speed in Km/hr (white text) with "Green" bounding box shown in the figure (8).

Table 7. The different videos with resolution 480 x 320, Frame rate – 25 Frames/ Second. Method-1 [9], Method-2 [10,11].										
Sr. No.	No. of Frames in Video	Recall			Precision			F1		
		Method 1	Method 2	Presented Method	Method1	Method 2	Presented Method	Method1	Method 2	Presented Method
1	430	0.78	0.63	1	0.78	0.78	0.72	0.78	0.7	0.84
2	496	0.7	0.7	1	0.88	0.78	0.78	0.78	0.74	0.87
3	205	0.7	0.54	0.92	0.82	0.7	0.71	0.76	0.61	0.81
4	567	0.84	0.59	1	0.84	0.78	0.8	0.84	0.68	0.89
5	205	0.86	0.72	1	0.86	0.72	0.78	0.86	0.72	0.88
6	292	0.75	0.25	1	0.86	1	0.8	0.8	0.4	0.89
7	224	0.84	0.67	1	0.63	0.8	0.75	0.72	0.73	0.86
8	630	0.75	0.55	1	0.75	0.92	0.8	0.75	0.69	0.89
	Average	0.7775	0.58125	0.99	0.8025	0.81	0.7675	0.78625	0.65875	0.86625

Figure 8: VSM using NVIDIA Jetson

6.6 Traffic sign detection & recognition

Figure 9: Traffic sign detection & recognition using Haar cascade (night time duration)

Figure (9) represents "No Parking" traffic sign detection and recognition for night-time duration with the help of Haar Cascade. There are a total of fifteen different sign detection and recognition possible for real-time video. The results are tested for captured video by mobile handset with bike-rider.

6.7 Object detection & recognition

Table 8. Shows comparison of our dataset with the COCO dataset for Botad video – 1920 x 1080 Resolution, 21 Frame/Second.

Car		Bike		Three-wheeler		Human	
Own	COCO	Own	COCO	Own	COCO	Own	COCO
1(0.97)	1(0.58)	1(0.99)	Person(0.95)	1(0.98)	Truck(0.86)	1(0.99)	Person(0.99)
2(0.98)	2(0.93)	2(0.98)	Motorcycle(0.55)		Train(0.51)		
3(0.99)	3(0.99)		Person(0.95)		Motorcycle(0.56)		
4(0.99)	4(0.99)	3(0.99)	Motorcycle(0.73)	2(0.91)	Bus (0.68)		
5(1)	5(0.99)		Person(0.75)		Truck(0.93)		
6(0.99)	6(0.95)	4(0.99)	Bicycle (0.7)				
7(1)	7(0.99)		Person(0.75)				
8(0.99)	8(0.99)	• Haar cascade provides results with a fixed window size.					
9(0.98)	9(0.98)	• Yolo method compares the accuracy of our dataset with the coco dataset.					
10(0.90)	10(0.99)						

Table 8 shows our dataset for object detection and recognition work well under day/night conditions and compare the accuracy of object recognition with the COCO dataset. Figure (10) detect and recognize human, bike, a car with its efficiency for Botad (city), Gujarat, during day-time.

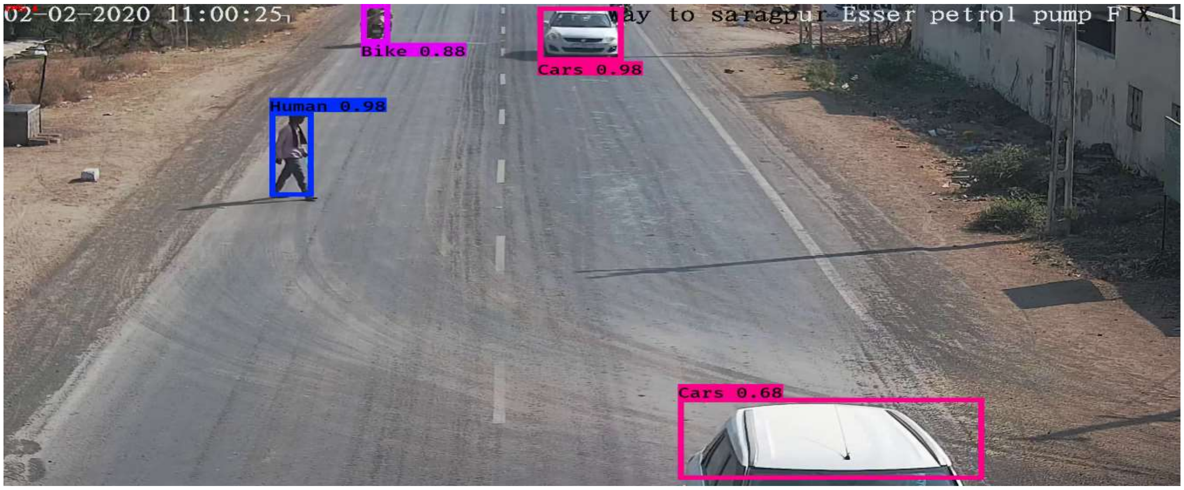

Figure 10: Object detection & recognition using YOLO for Botad city, Gujarat

7 Achievements with respect to Objectives

The design of a real-time traffic management system using computer vision for smart cities is developed as per the objective. The research work is published in peer review Web of Science indexed journals, Scopus indexed journals, IEEE internal conferences, Springer Book Chapter.

8 Conclusion

In this research work, Hough transform, edge detection, Statistical block-matching approach, vehicle density value, different morphology operation, Kalman filter, Euclidean distance, inter-frame difference, modified 3-frame difference method, color image segmentation, Haar cascade, Yolo, machine learning and deep-learning methods are tested to improve the different applications of ITS. User-friendly, car-parking android app is developed for multi-camera, multi-location parking system. All these applications are developed using Matlab, OpenCV and Python. Raspberry pi board is used to develop a prototype model for parking as well as ATLCS. NVIDIA Jetson Nano board is used for the real-time vehicle speed measurements. The computational time is calculated for each application and it is observed with the NVIDIA Jetson board computational time is very less. In this research work, different applications for ITS are developed and their performance is tested using standard benchmark performance parameters for the evolutionary growth of smart cities.

9 Publication

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[2] Janak Trivedi, Dr. Mandalapu Sarada Devi, and Dave Dhara, "OpenCV and Matlab based Car Parking System Module for Smart City using Circle Hough Transform," International Conference on Energy, Communication, Data analytics Soft computing **(ICECDS),** SKR, Engineering College, Poonamallee, Tamilnadu, India, IEEE conference record #42120. 2017, p. 2461-2464, DOI: 10.1109/ICECDS.2017.8389893. (**Available IEEE Xplore Digital Library**- https://ieeexplore.ieee.org/document/8389893).

[3] Janak Trivedi, Dr. Mandalapu Sarada Devi, and Dave Dhara, "Vehicle counting module design in small scale for traffic management in smart city," IEEE's 3rd International conference for Convergence in Technology **(I2CT)** Pune, 6-8 April 2018, Hotel gateway (TAJ), Hinjewadi-411002, Maharashtra, India, IEEE conference I.D. -43278, 2018, p. 1-6, DOI: 10.1109/I2CT.2018.8529506. (**Available IEEE Xplore Digital Library** - https://ieeexplore.ieee.org/document/8529506).

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10 Patent

[1] Janak Trivedi, Mandalapu Sarada Devi, Dhara Dave and Brijesh Solanki, “Parking Management System”, Indian Patent, Application Number: 202021039830, Application Date: 16/09/2020, **Status: Published.**

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