

Modeling, Design and Analysis of Intelligent Traffic Control System Based on Integrated Statistical Image Processing Techniques

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Abstract—Traffic congestion is a growing problem in urban areas nowadays. In this paper, a system is developed to control and monitor the congestion of traffic. The main motivation is to detect the presence and absence of vehicles on the road using statistical approach integrated with conventional image processing techniques. For this purpose, we have developed a “Probability Based Vehicle Detection (PBVD)” algorithm based Vehicle Detection System (VDS) integrated with post - processing subsystems to form a complete traffic control system. The system has the capability to obtain vehicle statistics during controlling traffic. Simulations are performed by developing complete prototype traffic architecture. Comparison is done using the result acquired from prototype system and processing a real time video of traffic scene. Simulation results show the effectiveness of the proposed scheme.

I. INTRODUCTION

Traffic control has been a topic of research from the past few decades. Management of large traffic in metropolitan areas is not a trivial problem and requires a careful thought out planning and control. Besides, increasing road widths or making by-pass lines, the available technological assets can be optimized to manage the intercity traffic. They allocate enough resources to effectively control the urban traffic. Additionally, their operation and maintenance cost are low.

Traditionally, lamps are used to control the traffic at intersection. Every lane is allocated a fix timer in which the vehicles are queued and when the timer expires vehicles are allowed to pass by. There is limited intelligence involved in such systems. Magnetic loops were another method to detect the presence of vehicles on the road.

Beside fix timers and magnetic loops there are other methods developed in the recent years for monitoring and efficient control of traffic. These involve the use of image sensors and incorporating the techniques of digital image processing in the available hardware platforms. Image sensors can be used for diverse purposes such as: Monitoring vehicle flow on a given lane, calculating speed, crash detection, Automatic Number Plate Recognition (ANPR) etc.

When controlling the intercity traffic using camera controlled systems there are some constraints that must be taken into considerations: Detecting vehicles in the

scene require description and discrimination from the background. This is normally called in literature as, defining Object of Interest (OOI). To efficiently control the process, requires background modeling techniques [1]. Other constraints are environmental variations such as illumination, fog, temperature, wind blows etc.

Previous approaches process the whole two or three dimensional plane for object detection and isolation from the background [2, 3]. Background subtraction for object detection was therefore the main constituent. However background subtraction performs poorly in case of outdoor environment where environmental variations demand a robust background update algorithm [4]. Ultimately, a vigorous background model needs to adapt quickly to environmental variations and therefore it is a separate research field in its own [5].

To tackle the aforementioned constraints, in this paper we propose an intelligent system for the control of traffic. The system incorporates the integration of statistical and digital image processing techniques. It is capable of controlling the traffic and at the same time gives us the road statistics. Moreover the system has the provision of collecting data about the vehicles.

The rest of the paper is structured as follows: Section II discusses the related work. Section III presents problem description followed by vehicle detection in section IV. System design is elaborated in section V. Section VI shows experimental results and finally section VII concludes the paper.

II. RELATED WORK

With the advancement in science and technology, it is now possible to monitor and control the large urban traffic by optimizing the available technological resources. In the following discussion, some of the state of the art work done for controlling traffic is presented.

An intelligent system for the control of traffic light and density has been proposed [6]. The system uses IR (infrared) sensors for detection and microcontroller for controlling of light signals. However, this system poses certain limitations. First, infrared sensors have a very short range. Secondly, most of the infrared light is absorbed during the fog.

A system for the estimation of traffic parameter using mobile phone counts for measuring traffic density has been proposed [7]. In this method vehicles containing

mobile phone entering and exiting the cells were counted. Based on this counting a statistical measurement is made about the number of vehicles.

An offline system for the estimation of traffic has been proposed in [8]. In this method, a video film of road scene was captured and then analyzed frame by frame for the existence and nonappearance of vehicles. An indication of the heavy traffic was given once the number of vehicles exceeds the specified threshold.

Traffic data collection has been done using visual sensors. This type of data include: number of cars, their sizes, orientation and appearance [9, 10]. A novel approach has been proposed for design of intelligent traffic control system in [11]. Basically it's a hybrid system in which mainly the traffic is controlled at the intersection, incorporating the techniques of image processing and fuzzy logic.

In [12], the author has developed a Mobile Intelligent Traffic Control System (MITCS) for controlling intercity traffic in Taiwan.

The control of traffic flow based on Area of Interest (AOI) using vehicle queue length and projection of two dimensional coordinates on three dimensional planes has been studied [13].

III. PROBLEM DESCRIPTION

The problem description is two folds: First, given a static camera mounted on the pole above the road, the task is to detect the absence and appearance as well as the number of vehicles if present on the road in a diverse environment with uncertain background. This is not a trivial problem as it involves the information about the lane region and background.

Secondly, an autonomous system is designed to detect, classify and display traffic on a given route. Furthermore, the system is made to adaptively control the flow of traffic in a given diverse and challenging environment.

To tackle the first problem an adaptive background modeling technique is exploited assuming that the road conditions vary linearly with time. Moreover, to detect the presence and absence of vehicles a probabilistic approach based on histograms of initial and current frames is used.

In order to overcome the second problem, a complete system architecture and algorithm is developed by using mathematical functions.

IV. VEHICLE DETECTION

To detect the attendance and absence of vehicles on the road, a description of vehicles feature and road profile is required. The knowledge of background is the most crucial component in detection process. Moreover, lane extraction will facilitate the detection of vehicles on the road. Since, in real time traffic applications we require efficient result with less time; therefore background modeling techniques are not appropriate.

Let us consider that the camera is static and the environment varies monotonically, we use the following equation for background update:

$$B_i = \alpha \times B_0 + (1 - \alpha)I_i, \quad 0 \leq \alpha \leq 1 \quad (1)$$

B_i is the background for i th frame I_i , B_0 is the initial background and α control the rate of update.

To detect vehicle on the road, a probabilistic approach beside the conventional approach of frame subtraction is used:

$$P_i(k_L) = \frac{n_L}{N} \quad (2)$$

where,

$P_i(k_L)$ is the probability that L^{th} intensity pixel having intensity k_L occur in the frame i , n_L is the number of occurrence of k_L intensity pixel, N is the total pixels in an image, i.e. $N = m \times n$.

If there is some vehicle present on the road the number of pixels with L^{th} intensity will change from n_L to n_L' and hence the probability from $P_i(k_L)$ to $P_{i+1}'(k_L)$:

$$P_{i+1}'(k_L) = \frac{n_L'}{N} \quad (3)$$

$$\Delta P_L = |P_{i+1}'(k_L) - P_i(k_L)| \quad (4)$$

$$T = N \sum_{L=0}^{255} \Delta P_L \quad (5)$$

To simplify calculations, we make a use of histogram and relate it with the above equations:

$$h_i(k_L) = n_L \quad (6)$$

$$h_i(k_L) = N \times P_i(k_L) \quad (7)$$

Thus:

$$|P_{i+1}'(k_L) - P_i(k_L)| = \frac{|h_i(k_L) - h_{i+1}'(k_L)|}{N} \quad (8)$$

$$\Delta P_L = \frac{|h_i(k_L) - h_{i+1}'(k_L)|}{N} \quad (9)$$

$$T = \frac{1}{N} \sum_{L=0}^{255} |h_i(k_L) - h_{i+1}'(k_L)| \quad (10)$$

The resultant value of T is compared with the threshold " t " empirically calculated. If the value of T is greater than t it will indicate the presence of the vehicle in the scene and vice versa.

Since, the presence and absence of vehicle is similar to tossing an unbiased coin therefore we define the following function:

$$V_i = \begin{cases} 1, & T > t \\ 0, & else \end{cases} \quad (11)$$

Having discussed about the vehicle detection the next section will illustrate the system design.

V. SYSTEM DESIGN

The system adopted is divided into four major components:

- A. Vehicle Detection System (VDS)
- B. Vehicle Counting and Classification System (VCCS)
- C. Traffic Signals Control System (TSCS)
- D. Data Display System (DDS)

Fig. 1 shows the overall operation of proposed system. The vehicle detection system is used to monitor for the presence and absence of vehicles on the roads. The data collected by vehicle detection system is fed to the vehicle counting and classification system. The system analyzed the received data and accordingly makes decision about the traffic signals. Also the data is sent to the display device for displaying the road conditions, such as the number of vehicles, the number of pixels each vehicle contain and classification of vehicles into small, medium and large size. In the following sections we will discuss the components of the system design.

A. Vehicle Detection System

The Vehicle Detection System (VDS) is based on Probability Based Vehicle Detection (PBVD) algorithm. The algorithm starts with the initialization of control parameters followed by frame capturing operation. The capture frames are in true color format which is then converted to monochrome image. After, vehicle detection is triggered by calculating value T from the sum of absolute histogram subtraction between the reference and current frame. If T become greater than the empirically predefined threshold value " t " then post processing is done to extract vehicles. This is done by subtraction of reference frame from the current frame followed by edge detection, binary thresh – holding, dilation, erosion and labeling operations on the differential frame.

Afterward, area calculation is used to separate vehicles from the redundant noise if present. Area calculation is more immune to noise as compared to other techniques. Finally the detected vehicles are sent to Vehicle Counting and Classification System (VCCS) for counting and classification of vehicles. At the end of the algorithm the reference frame is set accordingly and the process is repeated.

B. Vehicle Counting and Classification System

Data acquired from the VDS is labeled. After labeling, the numbers of pixels each labeled vehicle contain are counted and accordingly the vehicles are categorized into small, medium and large vehicles. This data is then sent to the Data Display System (DDS). Also in parallel, the numbers of labeled vehicles are counted and sent to Traffic Signal Control System (TSCS).

C. Traffic Signal Control System

After receiving the vehicles statistics from VCCS, the Traffic Signal Control System (TSCS) compare the number of vehicles on both sides of the roads and accordingly make a decision as to which side of the road should be given priority. If both of the roads contain the same number of vehicles then equal time will be given to both lanes of the road.

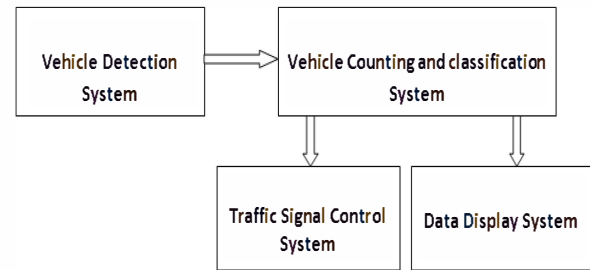


Fig.1 System Design

D. Data Display System

The Data Display System (DDS) display the total number of vehicles, the number of pixels each vehicle contain, the number of vehicles fall into each category, and the priority given to road. In general any category for vehicle classification can be made however; we have categorized the vehicles into three categories, small, medium and large.

VI. EXPERIMENTAL RESULTS

The experiments were performed first in a standard controlled environment with prototype traffic control system as shown in Fig.2. The cameras used in this work are standard Logitech C110 cameras. The traffic was generated using remote control cars. At the beginning, both lanes lamp indications are red (to stop vehicles). When vehicle is detected by any of the camera it is sent to VDS which uses PBVD algorithm to process and extract vehicles from the image. The parameter α for background update was set to 1×10^{-3} , whereas the value of threshold " t " for histogram comparison was set to 300. The processing is done using MATLAB® software for both controlling the external cameras and serial connected indication lamps.

Fig. 3 shows the DDS system for displaying road conditions and statistics.

Fig. 4 – 6 shows the complete process of extracting vehicle from the scene using the prototype architecture. As can be seen in Fig. 4 – 6, our prototype system gives accurate results even in the presence of noise. Since, maximum area calculation does not involve any shape distortion process; therefore the final results are very efficient as can be seen in Fig. 6.

After testing the proposed scheme on prototype traffic architecture, the system performance is then evaluated on a real time video of highway traffic and compared both the results. In processing this video we did not have any background information and thus it provide a challenging task of object detection. This is shown in Fig. 7 – 11. Fig. 7 shows the current frame. Fig. 8 shows the result after frame subtraction. Fig. 9 shows the resultant image after edge detection and binary dilation. Fig. 10 shows the required image after binary erosion, labeling and area calculation operations. Finally Fig. 11 shows the detected objects. Fig. 12 depicted the spread resulted from absolute histogram subtraction of the reference frame and the current frame.

After comparing Fig. 4 – 6 with Fig. 8 – 10, it is noted that in real scenarios object shape is distorted during

processing of a real time video. This is mainly due to edge detection and morphological operations (dilation, erosion, hole – filling). Since the main work is focused on detection and extraction of objects from the scene, we noted that in both scenarios, the proposed system gives us satisfactory results. Moreover, the area calculation operation after labeling operation helped in extracting vehicles in the presence of noise.



Fig. 2 Prototype of Proposed System

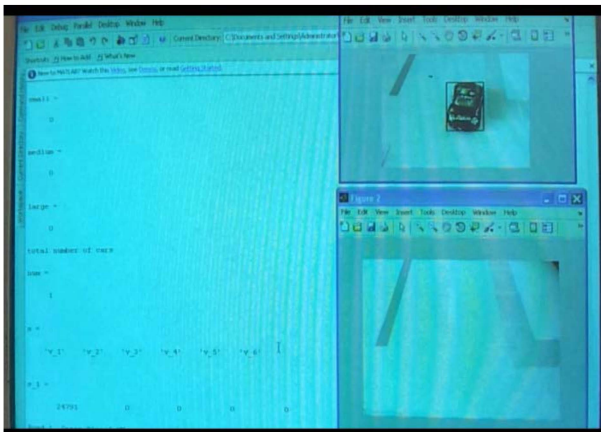


Fig. 3 Data Display System (DDS)

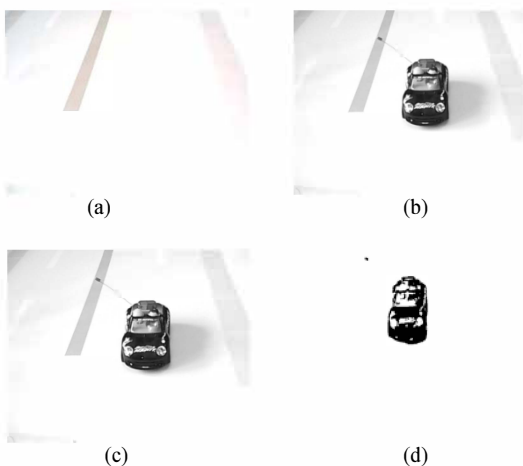


Fig. 4 a) Image of empty road b) image of the road containing car c) image enhancement after median filtering d) image after frame subtraction

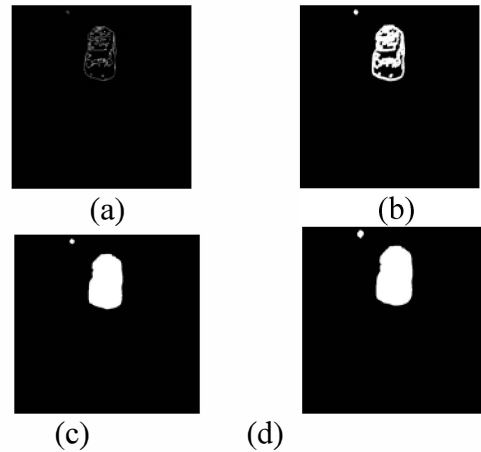


Fig. 5 a) Image after edge detection b) Binary conversion and binary dilation c) Binary Hole Filling d) Binary Erosion



Fig. 6 a) Area Calculation b) Final Result (Detected Objects)



Fig. 7 Current frame



Fig. 8 Frame subtraction



Fig. 9 Edge detection and binary dilation



Fig. 10 Resultant image after binary hole filling, erosion and area calculation

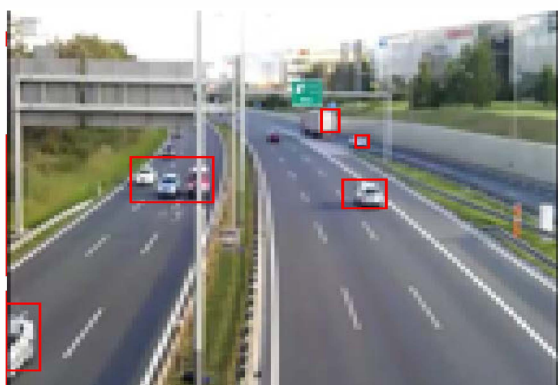


Fig. 11 Final result

VII. CONCLUSION

In this paper, an intelligent traffic control system is proposed for monitoring and control of intercity traffic. It is then tested using prototype traffic architecture and by processing a real time video of a high way. The final results are satisfactory and show that the system can cope with a noisy environment. Furthermore, we found that morphological operation greatly distort the shape of object and so there is some need of restoration techniques to retain the object shape after final detection.

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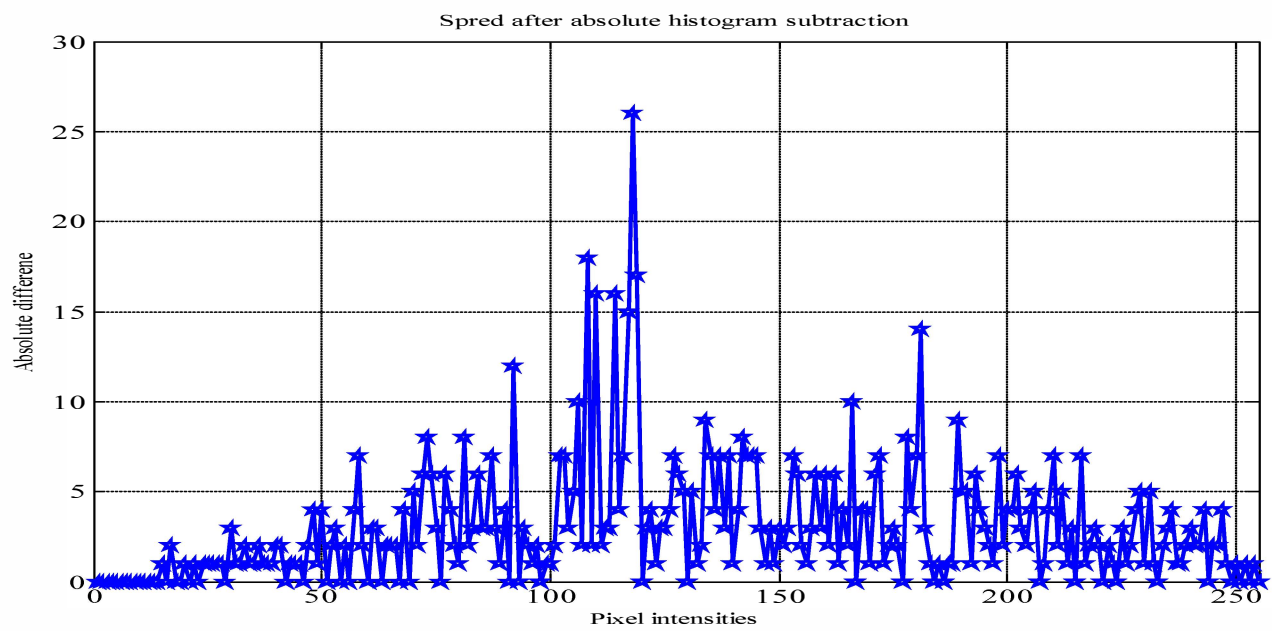


Fig. 12 Spread after absolute histogram subtraction