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Intelligent Traffic Signal Control using Image Processing

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Abstract: With the world moving towards smart cities, one of the major problems faced by almost all of cities is that of vehicular road traffic congestions. Conventional methods have proved to be of little use in this domain. The number of vehicles is ever increasing while the city infrastructures are developing at a much slower rate. This paper attempts to address the problem of traffic congestions caused at traffic signals.

The traffic light durations in the conventional methods have been constant which turns out to be a big drawback. In this paper we show how image processing can be used for managing this. It also demonstrates how the durations can be changed dynamically using this method and what implications it will have. The traffic is analysed through data collected from cameras and depending upon the volume of traffic, the traffic light durations are set.

Keywords: intelligent traffic management; image processing; smart cities; smart traffic signal;

I. Introduction

Traffic management is one of the most critical issues faced by any cities. With growing purchasing capacity of citizens and for the luxury that it offers, the number of vehicles is increasing exponentially. What adds to this ever increasing number of individually owned vehicles is the poor infrastructure and management of public transport available. The Indian government records [1] reflect this situation perfectly. The number of vehicles newly registered in the year 1951 was 306, in the year 1975 it was 2472, in the year 2000 it was 48857, while in the year 2011 it rose to a whooping number of 141866. Thus, it can be seen that the increase in the number of vehicles has been exponential. However, the systems devised to control this traffic have gone through up gradation at a much slower pace compared to this. The traffic signals used today are more or the less same those were used in the 1990s decade. They might have undergone aesthetic changes, but technologically they have hardly changed. The conditions can get even worse if this traffic management is done by a human, traffic cop. Thus, the traffic problem needs a state-of-art technology based solution.

The time durations for which a traffic signal turns red, yellow and green have been fixed for that particular signal traditionally. However, the traffic flow is very dynamic and never uniform. As a result many times, a lot of 'green' duration of a traffic signal gets wasted. That is, the signal has turned green but there are no vehicles coming in from that particular side. This leads to unnecessary delay and also increase in congestions on the remaining sides of the road crossings. Instead of acting as a flow controlling mechanism sometimes they, in fact, lead to biased traffic flow leading to congestions on certain sides. If these timings are well managed, it will lead to a smoother flow of traffic and result in time saving too. Thus, the relative traffic volumes on all sides of the roads need to be analysed. Whichever side has more flow should get longer duration of 'green' signal time.

Image processing is a powerful tool that can serve this purpose. Digital image processing is basically analysis and manipulations done on an input image from getting various attributes of image to detecting objects in it. It is used widely across various disciplines of sciences and engineering such as biomedical analysis, astronomy, surveillance, robotics, weather monitoring among many others. The analysis can be done in real time as well as post processing. However, real time analysis needs equally capable software and hardware platforms as well very optimised programming practices. Also, image processing can be done on images captured indoor as well as outdoors. While the indoor images have the benefits of controlled lighting conditions outdoor images pose a challenge due to variance in lighting. Especially during the night time it is very hard to capture images without using flash. The widely used solution for this is inclusion of infrared (IR) lights to illuminate the scenes in absence of sufficient natural light. The real time images taken from cameras can be used to monitor traffic volumes.

Thus a vision based system seems to be a good solution to address this problem. In a vision based system the main steps to be carried out would be – acquisition of images in real time, analysis of images, estimation of traffic flow on all sides on the traffic signal and setting appropriate timing intervals.

Given the gravity of the problem and the challenges posed by it, the idea of developing an autonomous traffic controller has grabbed the attention of many researchers around the world. More and more people are working on making a stable and robust system that will dynamically change the traffic sign intervals.

II. Related Work

Currently, in most of the cities in the developing nations, the traffic sign timings are set based on some heuristics which may or may not be reliable. In most of the cases no sensor systems are used and the heuristics are purely based on human observation. As a result they tend to be unreliable.

The Three-phase traffic theory [2] was given by Boris Kerner explaining the dynamics of traffic. Kerner describes three phases of traffic as- free flow, synchronized flow and wide moving jam, as opposed to the classical theory which only the free flow and congested traffic phases. SQLStream has developed a SmartCity StreamApp [3] that gives real time traffic alerts on mobile phones of users so that they can decide their routes.

In [4] Bhadra et al. have used agent-based fuzzy logic technology for traffic control situations involving multiple approaches and vehicle movements. Agent technology is implemented based on real-time data to produce this dynamic traffic system. Number of cars at any particular time instance on a specific lane and clock time are considered as decision making parameters. Lane status is considered as three types such as busy, moderate, and idle. Real-time data is collected with specific time intervals. The collected data is processed by the respective agent(s) performing specific operations. Fuzzy logic is utilized as mathematical model for implementation of agent technology. In [5], the author suggests an Internet Of Things (IOT) based solution using radio frequency identification (RFID). Tyagi et al. have shown a different approach in their work [6], in which they analyze the cumulative data of acoustic signals obtained from single microphone installed by the roadside. Analyzing the signal, they categorize the traffic into 3 different categories – jammed, medium flow and free flow. Hazrat Ali et al. Present a vision based approach [7] in which they collect data from cameras at different locations and different times using their Automatic Road Surveillance System (ARSS) to control the Traffic Signal Light (TSL). Sinhmar gives an IR sensor based approach in [8]. However given the volume of traffic in real time conditions and the capability of IR, it cannot be regarded as very reliable.

Antonio Ferna'ndez-Caballero et al. [9] presented a visual application which allows a study of behaviour of traffic on major roads (more specifically freeways and highways), using a video camera mounted on a relatively high places with a significant image field as a surveillance device. Reinartz et al. [10] give an approach of traffic monitoring from images taken from airborne cameras. They present method for determining several traffic parameters for single vehicles and vehicle groups involves recording and evaluating a number of digital or analog aerial images from high altitude and with a large total field of view. This allows capture of the immediate traffic dynamics for the recording area in considerable detail over a large region.

J.W.-K. Hong et al. [11] presented the design and implementation of a portable, Web-based network traffic monitoring and analysis system called WebTrafMon, which provides monitoring and analysis capabilities not only for traffic loads but also for traffic types, sources and destinations. Zhigang Zhu1 et al. [12] presented a novel approach to automatic traffic monitoring using 2D spatio-temporal images. A TV camera is mounted above a highway to monitor the traffic through two slice windows, and a panoramic view image and an epipolar plane image are formed for each lane. E. Planas et al. [13] was going to set up prototype of a new operational system for monitoring the transportation of dangerous goods in Europe based on regional responsibilities. This concept, based on systems used in air traffic control, aimed to provide civil security centers with real-time knowledge of the position and contents of dangerous vehicles circulating in their area of responsibility, and, in the event of a dangerous situation, to issue warnings, alerts and crisis management information, thereby allowing intervention teams to react immediately with maximum safety. Jen-Chao Tai et al. [14] presented an image tracking system and its applications for traffic monitoring and accident detection at road intersections. Locations of motorcycles as well as automobiles are obtained in real time using the active contour model approach. Image measurement is further incorporated with Kalman filtering techniques to track individual vehicle motion.

Xiao et al. [15] took global unique EPC code as identity identification of vehicles instead of vehicle license plate and utilized RFID reader to read EPC code by RF electromagnetic wave. They obtained positioning information of vehicles by using GPS technology.

III. NEED

As can be seen from the discussion above, a need of real time system is needed to control the traffic signs. The system should be able to collect visual data using cameras mounted at appropriate positions. The data should then be processed immediately so as to estimate the traffic sign durations that need to be set at a particular traffic signal for a particular direction. The cameras should also centrally connected to a computer so that the traffic signals work in synchronisation.

IV. PROPOSED DESIGN

On studying all of the previous works cited above, I propose a holistic approach to have an intelligent traffic management system. There will be cameras at all traffic signals which will monitor the traffic incoming from various sides. The image data sequences collected from the cameras will be processed in real time to quantify the volume of traffic in a particular direction. The timings of the traffic signals will be dynamically set depending upon the incoming volume from that direction. The side having more traffic volume will be allotted longer duration of 'green time' compared to others. This will avoid wastage of 'green signal time'. Four cameras will be set on each cross road which will be connected to a single computer that will perform all the processing.

a) *Camera specifications and positioning*

The camera used is surveillance camera used commonly by civic bodies. It is a closed circuit (CCTV) camera. IR illuminators can be used for night vision. The cameras have a standard H.264 video output which can be retrieved using a digital video recorder (DVR). The camera is interfaced to a computer which carries out the core image processing application. The camera gives output at 25 frames per second, that is, one image frame every 40 milliseconds. It needs a constant 12V DC power supply to work. The camera typically has a 1/3” CCD sensor as image capturing sensor with a response to light of 0.01Lux. The lens used are board lens which are available in variable focal lengths. Larger the focal length, greater the zoom and thereby lesser the field of view (FoV).

The cameras should be positioned at sufficient height so that their field of view contains at least 40metres stretch of road. Four cameras are thus positioned at four corners of the crossroad.

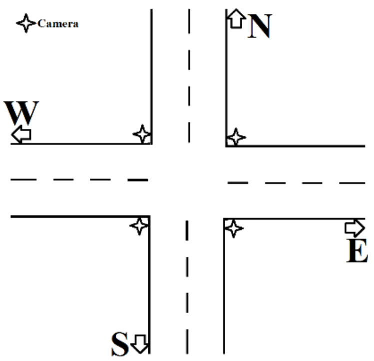

Fig1. The positioning of cameras

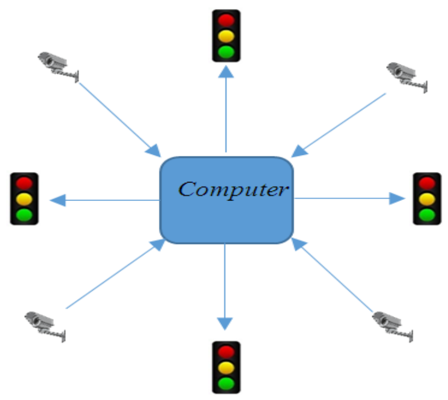

Fig 2. Simplified system architecture

b) Traffic volume estimation

This is the most crucial part of the whole design. The traffic volume estimation will be done on the basis number of vehicles detected in the image captured by camera. The image processing for this purpose includes various stages:

Image acquisition: Primarily videos are acquired from the mounted cameras. The video is split into individual frames. The frames will be in RGB colour space and in format with 8 bits of precision.

Colour space conversion: An RGB image is actually a superimposition of Red, Green and Blue frames. Thus a colour image takes up three times the memory required for a monochrome (single coloured) image. Thus any operation performed on a colour image takes thrice the time required for a monochrome image. As we do not need colour data and also as we need to system to do fast calculations, we initially convert the obtained colour image into a monochrome gray scale image. A gray scale image is obtained from a colour image by averaging the R, G and B values at every pixel in the image.

Edge detection: Edges are detected in an image by segmenting image based on abrupt changes in intensity [16]. There are three fundamental operations performed in any edge detection:

1. Image smoothening for noise reduction.
2. Detection of edge points
3. Edge localization

The image gradient operators are given by:

$$g_x = \frac{\partial f(x,y)}{\partial x} = f(x+1,y) - f(x,y)$$

And

$$g_y = \frac{\partial f(x,y)}{\partial x} = f(x,y+1) - f(x,y)$$

Depending upon the equations to be used, different masks are constructed. The mask is the convoluted with the given image to find edges in it.

$$\begin{array}{ccc} -1 & -1 & -1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{array}$$

(a)

$$\begin{array}{ccc} -1 & -2 & -1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{array}$$

(b)

$$\begin{array}{cc} -1 & 0 \\ 0 & -1 \end{array}$$

(c)

a) Shows mask for edge detection using Prewitt operator

b) Shows mask for edge detection using Sobel operator

c) Shows mask for edge detection using Robert operator

In our case we will use a more advanced edge detection algorithm, known as Canny Edge Detector (Canny [1986]). Compared to others, Canny's approach gives lower error rate, well localised edge points as well as single edge point response. This algorithm proceeds as follows:

1. Smooth the input image with Gaussian filtering.
2. Calculation of magnitude of gradient and angle images.
3. Apply non-maxima suppression to the gradient magnitude image.
4. Detect and link edges using double thresholding and connectivity analysis.

Contouring: Once edges are detected, segments are created in the image using contouring. Contouring distinctly identifies all individual objects detected from the edge detector. Various statistical manipulations can be carried out on contours to extract more information about the segmented parts.

Area based filtering: As is evident, edge detection will detect many unwanted objects in the image too (eg. Road dividers, poles etc.) which we do not want to be treated as traffic. Thus we implement area based filtering. The area of any contour can be calculated from its moments. The area of a contour is nothing but the total number of pixels enclosed by that particular contour. Thus, by calculating areas of all contours we filter out the too small or too big contours. Based on heuristics we set lower and upper limits of area which can be accepted as vehicles. This greatly reduces the erroneous detections caused otherwise.

Output: Thus, after performing all above calculations, we will get volume of traffic flow in terms of number of vehicles detected.

Fig 3.1 Original image

Fig 3.2 Gray scale image

Fig 3.3 Smoothened image

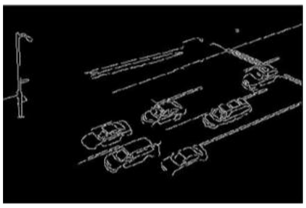

Fig 3.4 Edge detection

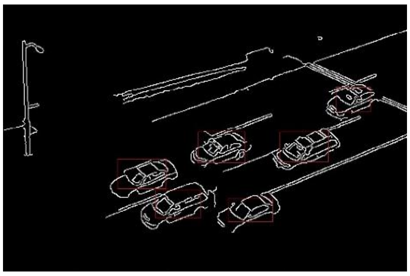

Fig 4. Detected vehicles

c) *Setting signal time*

As mentioned earlier all the traffic signals will be connected to a central computer. Depending on the traffic volume estimated corresponding to each of the signal, the timings will be set as follows:

- » Consider a cross road with its four roads along the directions north (N), east (E), south (S) and west (W) respectively.
- » A cycle is defined as the time duration between starts of two consecutive 'GO' (green) signal durations of the same signal.
- » Let the maximum allowed cycle duration of the signals together be 'T_{max}' seconds. (This is needed as we need to set a threshold on maximum time period of the cycle.)
- » Let t_N, t_E, t_S and t_W be the duration for which the signal turns green for the directions N, E, S and W respectively.
- » Let 'A' be the maximum area of vehicles that can cross the cross road in 1 second.
- » Let A_N, A_E, A_S and A_W be the areas of contours measured in the directions N, E, S and W respectively
- » Let A_{total} (= $A_N + A_E + A_S + A_W$) be the total area of contours (vehicles) detected from all the four cameras.

Thus now we have traffic volume equivalent to A_{total} at the crossroad and only A can cross in 1 second.

We calculate the cycle period (T) as

$$T = \frac{A_{total}}{A} \qquad \ldots..T < T_{max}$$

$$= T_{max} \qquad \ldots.otherwise$$

Now the individual signal times are calculated as

$$t_{N=}\frac{A_N}{A_{Total}}*T \qquad t_{E=}\frac{A_E}{A_{Total}}*T \qquad t_{S=}\frac{A_S}{A_{Total}}*T \qquad t_{W=}\frac{A_W}{A_{Total}}*T$$

V. CONCLUSION

Thus we have proposed a novel system for intelligent traffic signal control. We have successfully demonstrated traffic volume quantification using image processing techniques. Also, we have parameterized the traffic signal timings and shown how they can be set autonomously. In future we would like to have a network of all such cameras in the whole city. This would facilitate better control and co-ordination among different traffic signals in the city. Also, we plan to add neural networks to this system so as to detect and read the license plates of vehicles not following the rules.

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