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Macroscopic Traffic Flow Model based Dynamic Road Traffic Lights Management Framework

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Abstract

Background: Traffic management is an important tool of Intelligent Transportation System. The design of system for controlling the urban traffic dynamically provides not only the safety for pedestrians and motorists, but also saves the time and money. Method: In this paper, we describe a novel approach to manage the traffic light after measuring the accurate density with image mosaicking technique. Findings: This approach of measuring traffic density eliminates the use of conventional sensors which are sensitive to environmental changes. Even a single camera is not capable of measuring density accurately as gap between vehicles is important consideration. A single camera projection cannot capture the entire area between vehicles. So in this approach multiple cameras have been used to improve the accuracy of traffic measurement. The image mosaicking algorithm has been applied to measure one of the macro traffic flow parameter such as traffic density. The efficacy of proposed method has been evaluated, using MATLAB, AimSun and LabVIEW Software. Improvements: The result of extensive simulation indicates that this approach provides better performance in terms of increase the average moving time and decreases the average waiting time for traffic.

Keywords: Image Mosaicking, Macroscopic Traffic Model, Pixel to Pixel Correlation, Traffic Lights, Vision Sensors

1. Introduction

Traffic congestion is a major problem found in urban cities. For a traveler, congestion means loss of time, missing of opportunities and getting frustration. It also adversely impacts the industries due to productivity loss of the employees, loss of trade opportunities, delayed delivery. Common methods of conventional traffic light controls are time of day control; fix time control, area dynamic control. Artificial intelligence methods such as ANN1, Fuzzy Expert system2 and intelligent decision making system for urban traffic IDUTC3 are reported in literature. However no such a system has developed which meets the adaptive characteristics like the minimum time to take the decision for ON/OFF timings of RGY lights.

Many studies and statistics were generated in developing countries that proved that most of the road accidents are because of the very narrow roads and because of the destructive increase in the transportation means4. Traffic light is one of the most significant factors in the management of the traffic. Traffic light signs are that signs erected at the sides of the roads to provide information to road users. It has been proven that traffic signal timing and coordination of existing signals reduce significantly in traffic delay, energy, travel time and this consequently results in increased safety for the public5. Due to poor strength of traffic police, it is impossible to control traffic manually in all area of city or town. For this reason, researchers got interested in developing efficient real-time traffic signal control6. This idea of controlling the traffic light efficiently in real time has attracted many researchers to work in this field with the goal of creating automatic tool that can estimate the traffic congestion and based on this variable, the traffic sign time interval is forecasted. Analysis of traffic conditions showed that there are many fluctuations in the quantity of the vehicles

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approaching to a cross road for the same period of time. Therefore, the current automatic traffic light control using a timer which is commonly used in India at many cross roads is not realistic and such automatic tool is required to have more realistic, effective and efficient tool than the current one.

2. Traffic Flow Models

Traffic flow models can be studied by grouping them in several ways. The nature of traffic flow models can be different in terms of their application area, in terms of their level of detail, in terms of the time domain used to describe them (as discrete-time or continuous time models), and in terms of their stochastic or deterministic nature in the description of the traffic variables. Based on their level of detail, they can be categorized as microscopic, macroscopic, and mesoscopic traffic flow models. The description of these flow models is given as:

2.1 Microscopic Traffic Flow Models
Traffic flow models that treat and model the behavior of individual vehicles in a traffic network fall in the category of microscopic traffic flow models. Microscopic traffic flow models describe the physics of individual vehicles as they interact with the driver and the infrastructure. In such modeling techniques lane changes, the inter-vehicle distance, and the effect of neighboring vehicles to a vehicle are described. The main advantage of microscopic traffic flow models is that the behavior of the drivers and vehicles are described in detail. Therefore, they can provide relatively more information regarding the characteristics of the traffic flow (e.g., headway time or distance; position, speed, and acceleration of individual vehicles; heterogeneity of vehicles; and the like) than other types of models. The main limitation of microscopic models is that they require a large memory size and they are very slow when used for large traffic networks.

2.2 Macroscopic Traffic Flow Models
Macroscopic traffic models describe the collective vehicle dynamics in terms of the spatial vehicle density, the average flow, and average speed. Macroscopic traffic flow models deal with traffic flow in terms of aggregate variables (such as average speed, flow and density). These aggregate variables, which describe the behavior of the drivers or vehicles, are assumed to depend on the traffic conditions in the drivers’ (or vehicles’) direct environments. Macroscopic traffic models do not distinguish the behavior of individual vehicles in a traffic stream. So, in macroscopic models the simulation time and memory requirements mainly depend on the size of spatio-temporal discretization, but not on the number of cars. Therefore, macroscopic traffic flow models are suitable for faster than real-time traffic simulations. Another advantage of macroscopic traffic flow models is that they allow to simulate the traffic dynamics in several lanes by effective one lane models.

2.3 Mesoscopic Traffic Flow Models
Mesoscopic models describe the behavior of small groups of vehicles of a specific user-class classified by their position, velocity, and desired velocity at an instant of time. The mesoscopic traffic flow models describe the traffic flow in lesser detail than the microscopic models and in greater detail than the macroscopic models. In such models the vehicle or the driver behavior is not described individually, but in more aggregate terms. For example the same probability distribution functions can be used to categorize or describe the behavior of a vehicle or a driver in some range of time or distance. The mesoscopic traffic flow models can be grouped into three categories: head way distribution models and the gas-kinetic continuum models. Since the mesoscopic models combine some of the microscopic characteristics to macroscopic.

3. Proposed Traffic Management Framework

Figure 1 shows closed loop control system, in which comparator or error detector gives the information of average pixel to pixel matching of reference mosaicked
image and Current mosaicked image. Here controller is intelligent decision making algorithm which varies the timings of green/red lights as per density measured on road. In feedback loop, vision sensors named cameras has been used for capture the images of traffic. After capturing the images, the image passes though number of steps like saves the images, grey conversion, transformation, wrapping, compositing and finally mosaicked image formed. Figure 2 shows the schematic diagram of proposed framework on ‘+’ shape road. 4 web cameras of 8.0 Mega pixels have been installed on each side of road. It has been assumed that in W-E and E-W direction there are two lanes in each side as heavy traffic passes in these directions as compared to N-S and S-N which is having single lane due to low traffic on these directions. The proposed algorithm works in such a way when normal traffic is detected, the timings remains same as set earlier. But when algorithm detects traffic more than normal (normal traffic measurement range may be obtained from past data), timings of red/green lights varies accordingly. As macroscopic traffic flow model only deals with average density, average velocity and average speed of traffic but in this proposed framework only traffic average density has been considered as parameter of macroscopic traffic flow model.

Figure 2. Schematic macroscopic traffic flow model.

4. Design Criteria and Constraints

In the development of the dynamic traffic lights control system the following assumptions are made:

- The junction is an isolated four-way junction with traffic coming from the north, west, south and east directions.
- When traffic from the north and south moves, traffic from the west and east stops, and vice-versa.
- No right and left turns are considered
- The dynamic logic controller algorithm will observe the density of the north and south traffic as onside and the west and east traffic as another side.
- East-West lane is assumed as the main approach.

5. Image and Vision Computing (Mosaicking)

Image mosaicking is the process of smoothly piecing together overlapping images of a scene into a larger image. This operation is needed to increase the area of coverage of an image without sacrificing its resolution. Due to the limited size of digital images, it is sometimes not possible to include an area of interest in an image. In such a situation, overlapping images are obtained and the images are combined into a larger image through image mosaicking. An image mosaic is created from a set of overlapping images by registering and re-sampling all images to the coordinate space of one of the images. An image mosaicking system has to take into consideration the relation between the cameras, distances of the cameras to the scene, the scene content, and the characteristics of the cameras. As Shown in Figure 3. image mosaic process consists of three steps: Image transformation, image blending or warping and image compositing or stitching.

Figure 3. Flow chart for image processing.

6. Algorithm for Proposed Framework

Algorithm has following steps:
• Acquire the images from individual cameras during red light and saves them automatically in database.
• RGB Images are converted into gray scale images.
• Gray scales images are transformed into different projections to meet the properties of pixel to pixel.
• Projected images are warped or blended so that pixels of projected images perfectly match throughout the region.
• Blended images are stitched or composited to make one image called mosaicked image which gives the information of images taken from different angles earlier.
• Steps 1-5 repeated for reference image just after 2 seconds when red becomes ON.
• Algorithm waits until reference mosaicked image and current mosaicked image formed.
• Pixel to Pixel matching of both mosaicked images performed.
• The average matching of both mosaicked images gives the command to timers of green lights for varying the set time values.

Steps 1-9 executes during the red light so that timings of green light may be varied. For example if total time is given to red light + green light is 60 seconds and if traffic on N-S road is more than normal then timing of green light will be 50 seconds and timing of red light will be 10 second. The set timings are arbitrary values.

7. Pixel to Pixel Matching with Cross Correlation

![Image](Figure 4. Template matching of two mosaicked images.)

Pixel to pixel template matching is evaluated by calculation of normalized cross-correlation coefficient between the selected templates as shown in Figure 4. If normalized cross-correlation value is higher than a fixed threshold, the region is considered as corresponding to traffic light. For getting robust matching result, we performed template matching using normalized cross-correlation method and is described by distance measure or squared Euclidean distance:

$$d_{ij}(u,v) = \sum_{x,y}[f(x,y) - t(x-u, y-v)]^2$$  \hspace{1cm} (1)

Where \(f\) is mosaicked image and sum is over \(x, y\) under the window containing the feature \(t\) positioned at \(u, v\). In the expansion of \(d^2\),

$$d_{ij}(u,v) = \sum_{x,y}[f(x,y) - 2f(x,y)t(x-u, y-v) + t^2(x-u, y-v)]$$  \hspace{1cm} (2)

the term is constant. If the term is approximately constant then remaining cross–correlation term

$$c(u,v) = \sum_{x,y}[f(x,y)t(x-u, y-v)]$$  \hspace{1cm} (3)

is measure of similarity between the image and feature. The correlation coefficient overcomes some of difficulties like variation in image energy, range or size of feature, variation in lighting conditions etc., by normalizing the image and feature vectors to unit length, yields to cosine correlation coefficient

$$\gamma = \frac{\sum_{x,y}[f(x,y) - f_{x,y}][t(x-u, y-v) - t]}{\sum_{x,y}[f(x,y) - f_{x,y}]^2 + \sum_{x,y}[t(x-u, y-v) - t]^2}$$  \hspace{1cm} (4)

In Equation (4) denotes the mean value of \(f(x,y)\) within the area of template \(t\) shifted to \((u,v)\) which is calculated by:

$$f_{x,y} = \frac{1}{N_xN_y}\sum_{x,y\in t}[f(x,y) - f_{x,y}]$$  \hspace{1cm} (5)

Due to normalization, the use of Equation (4) for the calculation of matching degree is more robust than the other similarity measure like covariance or sum of absolute differences.

8. Experimental Results

To check the performance of proposed framework, Lab VIEW simulation test bed has been used as shown in Figure 5. In GUI ‘+’ type road has made with vision sensors to check the variations in timing of Red/Green lights whereas Figure 7. Shows the logic behind the constructed GUI.
Figure 5. Lab VIEW simulation test bed (GUI).

In Figure 6 traffic is allowed to go through W-E, E-W, N-S and S-N directions. Randomly traffic may be increased or decreased on any road to evaluate the performance of proposed scheme.

Figure 6. Test bed with AimSun.

AimSun is the platform which has been developed to improve the transportation system. This platform has been used to evaluate the performance. It also gives the information about traffic present on road in percentage.

Figure 7. Lab VIEW simulation (block diagram).

Figure 8 shows the two images captured at different projections. After processing these images, final mosaicked image is shown in Figure 9.

Figure 8. Two images captured at different projections.

Figure 9. Final mosaicked image.

To compare proposed technique with conventional techniques, a experiment has been performed on one vehicle. One of the vehicle is allowed to go to in W-E direction at 40Km/hr on AimSun test bed. Total time of 450 seconds is given to vehicle to check the covered distance. Randomly traffic density is applied on road to check the performance. The same conditions have been applied to IDUCT, FES, ANN techniques to check their performances. After simulate the experiment, it is found that vehicle when adopts Dynamic Road Traffic Management System (DRTMS) covers 4.6m distance in specified time period whereas distance covered by vehicle using techniques IDUCT, FES and ANN is 4.3m, 4.0m and 3.7m respectively.

Simulation results Shows average waiting time and moving times for vehicles. Whereas the time taken by vehicles when no distance is covered, is the time when red light becomes On and remains on for a time depends upon traffic present on road and execution of algorithm.
During this red light period decision making algorithm decides the timing of Green light for next cycle. As it can be seen in Figure 10 that proposed framework (DRTMS) increases the average moving time and decreases the average waiting time.

![Figure 10. Comparison chart of conventional techniques with proposed scheme.](image)

### 9. Conclusion and Future Work

Road traffic congestion is a central problem in most developing regions. Most urban areas have poorly managed traffic networks with several traffic hot-spots or potential congestion areas. In this paper, we study the problem of road traffic congestion in high congestion hot-spots in developing regions. We first present a simple image processing algorithm to estimate traffic density at a hot-spot using web-camera feeds. Based on analysis of traffic images from live traffic feeds, we show evidence of congestion collapse which last for elongated time periods. Our hope is that localized de-congestion mechanisms are potentially easier to deploy in real-world settings and can enhance the traffic flow at critical hot-spots in road traffic networks. We believe that this represents our initiative in development of low-cost, deployable strategies for alleviating congestion in developing regions. Based on the accurate dynamic traffic density measurement on road, intelligent technique to manage the traffic lights has been developed for the purpose of maximizing traffic throughput and minimizing average waiting time at an intersection.

Some artificial intelligent techniques like Fuzzy logic, FES, GA, PSO etc may be developed with image mosaicking for better decision making in short time.

### 10. References