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A Traffic Monitoring Based on Vehicle Density Estimation and Analysis for a Mixed Traffic Flow in a Transport Cross-road

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Abstract

The Traffic Monitoring System (TMS) is an important element in an Intelligent Transportation Sysstem (ITS) for a real-time traffict flow control, especially in a developing country like Vietnam with a mixed traffic flow of vehicles including motorcycles and cars. In our previous research work, the density and length of the vehicles occupied on the road have been determined in the area viewed by a mounted camera on the road. However in this paper, a proper method for traffict flow control in the actual transport scenario in Vietnam is proposed, which monitors vehicle density in the area beyond and in front of traffict lights, as well as in the cross-road area from the mounted camera to estimate the traffic density. The system implementation and experimental results showed the efficiency of the proposed method compared to other convenient ones, where the traffic light signals are fully controlled by the estimated vehicle density captured by the system camera.

Keywords: Traffic monitoring, Traffic light control, Cross-road, TMS, ITS

1. Introduction

So far, the estimation of transport flow solely based on the determination of the number of vehicles passing through a road section at a time and set up the corresponding timing of the traffic signals. In developing countries like Vietnam with a mixed flow of vehicles including motorcycles, the estimation of the traffic flow becomes a more complicated problem, since motorcycles can move in a jumble with cars as long as there is enough spaces or gaps simulated as in [1] but in Vietnam it is a more complicated task. Therefore, the traffic analysis based on counting the number of vehicles seems to be neutralized. In addition, classification of vehicles is also a challenge task [2]. This method however simulates and estimates the mixed traffic flow in the context of a university campus and therefore is not the case of the road context.

The method presented in [3] utilizes the approach of a synchronous control system as depicted where a green light system operates in the adjacent intersections like green waves with the aim to control and monitor the speed of vehicles on the roads for reduction of a jam and potential accidents, especially in the rush hours. However, this method estimates the control time for the traffic light systems at intersections, which are synchronous only, without taking into account of an adaptive adjustment of the traffic signals for a thorough traffic.

Another method in [4] uses Vehicular Ad Hoc Networks (VANETs) to estimate the vehicle stop time for each traffic light pair for timing. This method is not reliable because the data from the simulation scenarios can’t respond immediately to the traffic flow which is quickly increased in a short time. This method also has not addressed to the case when the vehicles accelerate or decelerate at the moment the signal lights change.

An automatic traffic flow control and monitoring has been focused so far by researchers, where traffic flow is estimated by using cameras mounted on roads to capture the vehicle traffic and analyse the flow instead of the conventional methods which typically utilize sensor devices for vehicle counting as in [5]. These methods however do not include the delay time for the vehicles waiting at a further distance to start moving at the moment to switch from red to green light signal can. The delay time in this case actually is small but it is significant compared to the switching time of the traffic light signals.

The method presented in [12] requires the addition of detectors is completely impracticable for developing countries or with mixed traffic flow, which can only be applied to developed countries by line car in a lane. Mostly at that time, detectors on upstream-line and detectors on stop-line will operate efficiently. This method used Fuzzy Logic Controller (FLC) to calculate the appropriate time for an intersection through vehicles stopping on red lights. The time was estimated by detectors far enough to calculate the

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length of each contain lane. This research also did not deal with sensitivity and how to set up detectors, when the detector is in the middle of two stop cars. The FLC was applied to use two cameras, distance between two cameras was 0.8m in [13]. This method was expensive in terms of infrastructure and systems. And the purpose of setting up these cameras were mainly to determine positions of the lower and upper detectors.

Many methods used a camera to monitor the traffic density of vehicles waiting in the red light signal and moving while the green light signal is on [9]. The cameras in this method are used to monitor the traffic density of vehicles waiting before the stop-line, which are mounted in perpendicular direction to the road surface for detection of unoccupied areas. However this method does not take into account the queue length of the in-line waiting vehicles, therefore it might not be suitable for Vietnam transportation scenarios.

The proposed TMS system in [11] by the authors used one CCD camera mounted to view from the rear of moving vehicles appearing in a distance from a viewed span of the camera to the stop-line of the cross-roads, which is denoted by L and statistically determined. The timing of the traffic light can be adaptively adjusted according to the estimated traffic flow which is based on the video sequence captured by the camera in its span on the road, where the gaps between the vehicles are used to determine the density of vehicles appearing in the camera span. However, this method focused on *L* area before the stop-line to estimate vehicle density. Therefore, in the actual transport scenario in Vietnam with a mixed vehicle flow, the timing control of traffic light signals might suffer ineffective setting.

This paper proposes a new idea based on the traffic video analysis including determination of queue length of all in-line vehicles beyond the traffic light as well as before the stop-line to estimate the vehicle flow and use for timing of the traffic light signals. Based on the roadway area found in the captured traffic video, which is occupied by the vehicles, the traffic density will be estimated and then the traffic light timing will be updated accordingly. This method allows to reuse the infrastructure of Vietnam transportation of Vietnam, which do not require to implement supporting devices as detectors, stereo camera etc.

This paper is organized as follow. The introduction part is followed by illustration of the proposed system implementation. The last part demonstrates experimental results, performance evaluation, discussion and future work.

2. Proposed System Implementation

The system implementation is based on setting camera model with the parameters of interest, which are described in Fig. 1. In this model, the height from the camera to the ground, the deviation angle of camera to the vertical axis, and the angle of camera view span are denoted by *h, δ*, respectively. In addition, *k* stands for the distance from the camera along its view direction to the road surface.

2.1. System model

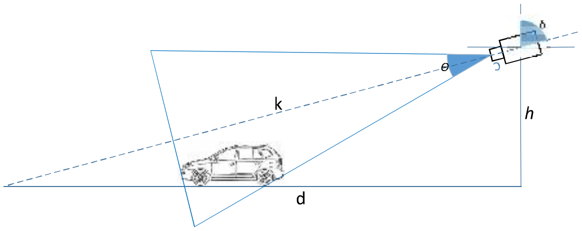

Fig. 1. Camera setup model

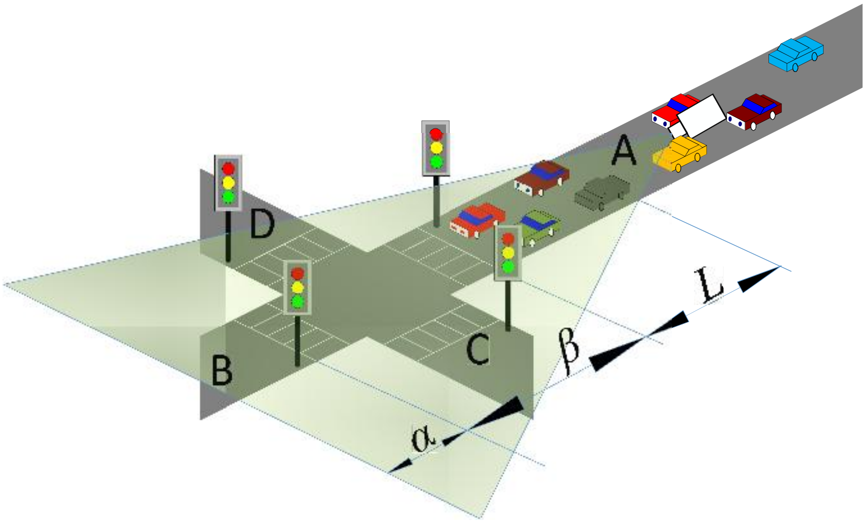

Fig. 2. System implementation model

The proposed implementation system model is designed to monitor the traffic flow of vehicles moving in road lanes which is based on the determination of the empty area left by occupation of the vehicles in the viewed span area of the mounted cameras beyond and in front of the given cross-road.

As illustrated in Fig. 2, the parameters L and α denote the lengths of in-line vehicles beyond and in front of the traffic lights, respectively and β in turn denote the width of the cross-road between the two opposite traffic lights. Fig. 3 demonstrates a practical transport scenario on roads in Vietnam with a typical mixed flow of vehicles, where L, α, and β have been mapped in correspondingly. For more effective processing, the sub-distances of α is further investigated which correspond to three areas denoted by $\Delta\alpha_n$, $\Delta\alpha_m$ and $\Delta\alpha_\infty$ respectively. While $\Delta\alpha_\infty$ is defined as the distance from the vanish point to the infinity and referred as non-vehicle area, $D_{vehicle} = \Delta\alpha_n + \Delta\alpha_m$ is the distance from the stop-line beyond the cross-road to the vanish point, where the existing vehicles may be detected. Vanish point is first localized by the furthest detectable moving vehicle in the given frame. Using the setup camera, the distance $\Delta\alpha_n$ of about 50% of $D_{vehicle}$ is determined by experiments which has determined best vehicle detection rate.

The proposed method consists of two main steps: 1) detection of the area occupied by the vehicles appearing in a frame denoted by $A_{occupied}$ and 2) determination of the area tracing the vehicle flow direction flow which has been passed the cross-road area which is denoted by A_{traced}.

2.2. Determination of $A_{occupied}$

In the camera based traffic management, vehicles were detected by adoption of adaptive background subtraction for real-time segmentation of moving regions in image sequences [6]. This method proposed to model each pixel as a mixture of Gaussians and using an on-line approximation to update the model, and then classify the pixel based on whether the Gaussian distribution which represents it most effectively is considered part of the background model. The pixels corresponding to the vehicle which have passed though the camera view are detected, traced and then synthesized in a given time period to eliminate the shadow from the sunlight or streetlight.

Fig. 5 shows the $A_{occupied}$ found from the vehicle flow which has been passed through and is marked by as a green area (GA). A given frame is first binarized by Otsu as in [7] and then $A_{occupied}$ is determined as a set of binary blocks which typically correspond to the vehicles appearing in the frame.

Fig. 3. Typical transport scenario with a mixed flow in Vietnam transport system

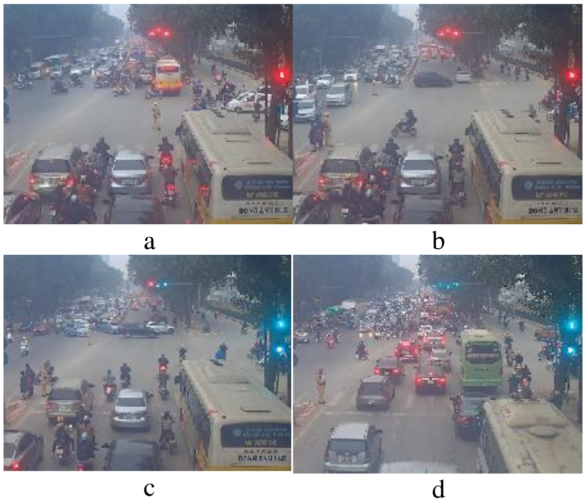
a
b
c
d

Fig. 4. Traffic light timing and vehicle density on the road. a) Red light starts; b) Red light ends; c) Green light starts; d) Green light ends.

Fig. 5. A video frame of a vehicle flow captured by the camera: a) Original frame; b) Its binarization; c) The area $A_{occupied}$ in the frame marked by green area.

Within the found GA, the traffic density is adjusted correspondingly from the horizontal bounded by L, $\Delta\alpha_n$, and β, and as shown in Fig. 3:

- L can be used to estimate vehicles density stopping before the stop-line.
- The ratio between the empty area left on $\Delta\alpha_n$ and the total area bounded by $\Delta\alpha_n$ will decides whether the vehicle flow can be continued moving in the cross-road.
- The empty area left on β is utilized to estimate the yellow light timing for the current phase to avoid a possible conflict with the opposite phase.

Since the occupied roadway is found by this simple method, the elapsing time is therefore significantly reduced in comparison to that in the conventional methods where utilize vehicle counting. In this system, the height and the view angle of the camera will be statistically calibrated to setup the view span.

2.3. Determination of A_{traced}

This paper refers the idea described in [8] for traffic flow density, however with few modifications to work with multiple road lanes with a mixed flow of vehicles, which is typical transport context in Vietnam. Usually vehicles move close enough and stop by the stop-line at a very near distance each to other, especially motorbikes. Therefore, the lanes on the road way which has been detected will be helpful in the estimation of the traffic flow. The Peak Hour Factor (PHF) is first evaluated by:

$$PHF = \frac{Hourly\,volume}{Peak\ flow\,rate\,(within\,the\,hour)} = \frac{V}{6\,x\,V_{10}} \quad (1)$$

where

V = hourly volume (*vehicle/h*), and

V_{10} = volume during the peak 10 min of the peak hour (*vehicle/10 min*)

The average travel speed of the vehicles in a distance L (*km*) is then determined by:

$$S = \frac{nL_e}{\sum_{i=1}^{n} t_i} = \frac{L_e}{\frac{1}{n}\sum_{i=1}^{n} t_i} = \frac{L_e}{t_a}, \quad (2)$$

where,

S = average travel speed *(km/h),*

L_e = length of the roadway segment *(km),*

t_i = travel time of the *i*th vehicle to traverse the section *(h),*

n = number of travel times observed, and

t_a = $\frac{1}{n}\sum_{i=1}^{n} t_i$ = average travel time over L *(h)*

One should note that L (*km*) is the distance from the viewed span of the camera to the stop-line at a cross-road as shown in Fig. 2. The traffic density is then given as follows:

$$D = \frac{V}{S}, \quad (3)$$

where

D = density *(vehicle/km),*

V = hourly volume – flow rate *(vehicle/h),* and

S = average travel speed *(km/h)*

The density of traffic vehicles can be calculated with a smaller unit kilo-meters. In this case, the camera can be clearly observed length of about 50 ~ 100 meters

$$D(vehicle\,/\,km) = \frac{1000}{spacing(m\,/\,vehicle)}. \quad (4)$$

The headway is defined as the time between successive vehicles as they pass a point on a lane or roadway, also measured from the same point on each vehicle. The headway can be easily measured with stopwatch observations as vehicles pass a point on the roadway, and expressed by:

$$Headway(s\,/\,vehicle) = \frac{spacing(m\,/\,vehicle)}{speed(m\,/\,s)}. \quad (5)$$

The flow rate is related to the average headway of the traffic stream, and expressed as:

$$Flowrate(vehicle\,/\,h) = \frac{3600}{headway(s\,/\,vehicle)}. \quad (6)$$

Information of the determined traffic density, length distance corresponding to the vehicle queue, and monitoring road sections will be used for automatic timing update on the traffic light system for a given cross-road rather than the use of traffic information only. In the real situation on the cross-road, the camera will be activated periodically for each cycle of time t to find the roadway and then start estimation of vehicle queue.

3. Experimental Results and Discussion

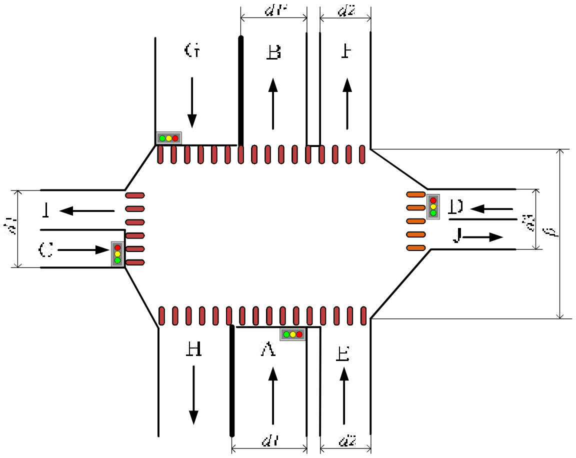

Fig. 6. Simulation scenario

As shown in Fig. 6, the simulation scenario is a actual 4-way cross-road with 10 lanes using 4 surveillance cameras which are mounted to monitor respectively lanes A, B, C and D from the distance L according to the system model in Fig. 2. In this real cross-road, the phase A-B is the lane of interest with the highest density compared to that of the remaining lanes, and all the lanes are controlled by the same timing for the traffic signals mounted on each phase. The real lane's widths in this cross-road are $d1$=10m, $d1'$=8.4m, $d2$=6.4m, $d3$=7m, $d4$=14m, $\Delta\alpha_n$= 68m, β=41m and L=10m, respectively, where the video resolution is 800x600 at sampling rate of 3 frames/per second.

Fig. 7 demonstrates few frames extracted from the surveillance video, which are used for testing the proposed algorithm on a typical transport mixed flow in Vietnam.

The yellow signal time is for transition between red and green signals, where the vehicles flow can ends without any conflict with the opposite phase. In this simulation scenario, the average speed of the vehicles is 20km/h, so the yellow signal works in the time duration of 7s.

Fig. 7. An example of 3 frames captured phase A-B from the surveillance video sequence and their corresponding binarized images.

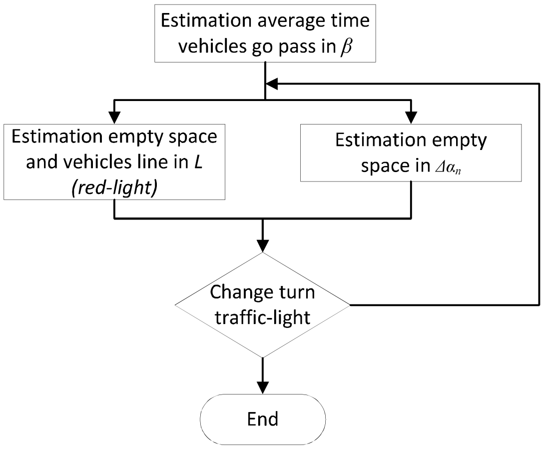

Fig. 8. Flowchart of system implementation

Fig. 8 illustrates the vehicle density occupied in the area bounded by L. The vehicle flow is supervised in 35 seconds time duration consisting of 23 seconds green signal (FROM 1st frame to 69th frame), followed by 3 seconds yellow signal (FROM 70th frame to 78th frame) and the last 9 seconds FOR red signal (FROM 79th frame to 111th frame). The area bounded by L corresponds to the peak density at the 28th frame or at 9.33s. When red signal starts to turn on, the area bounded by L corresponds to the highest density at the 67th frame or at 22.33s, and afterward the density decreases because the authors used subtraction background method to find out objects.

Once the red signal starts, all vehicles must stop before the stop-line, and these vehicles are considered as empty areas on the ground, which can be extracted utilizing the background subtraction method [6]. Therefore as shown in Fig. 8, the more empty area bounded by L increases and it is equivalent to the increased vehicle density in the cross-road.

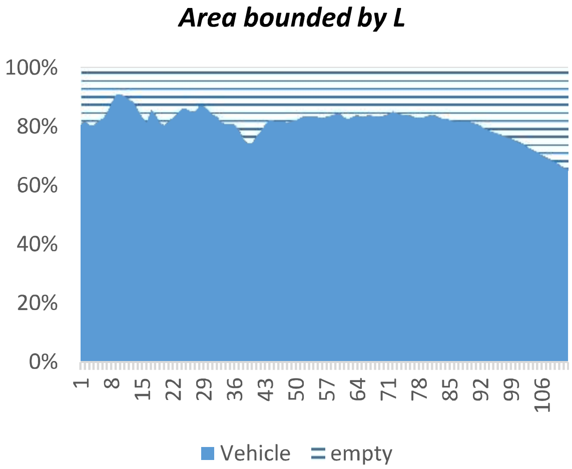

Fig. 8. Demonstration of vehicle density occupied in the area bounded by L in time duration of 35 seconds.

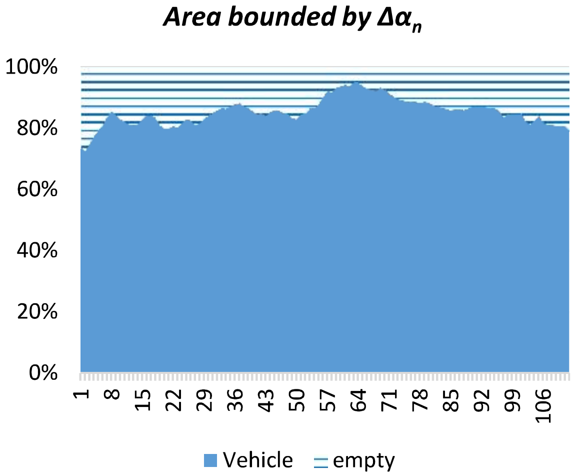

Fig. 9. Monitored vehicle density occupied in the area bounded by $\Delta\alpha_n$ in time duration of 35 seconds

Investigation on the area bounded by $\Delta\alpha_n$ as depicted in Fig. 9, it reaches the peak value at the 39th frame or at 8s on the green signal time duration. That means there should be a traffic congestion in this area and vehicles could not enter anymore. In that case, the information on the area bounded by β will be studied. As illustrated in Fig. 10, the percentage of the empty area on this are reaches 60% at 61th frame or at 21s, therefore the vehicles flow entering the cross-road from the opposite phase will be affected and delayed. Hence it is recommended to decrease the timing for green signal to avoid possible conflict in the next period.

Table 1. Performance in term of traffic light timing according to the estimated vehicle density.

Phase	Current Green light timing (s)	Updated green light timing (s)	Current Red light timing (s)	Updated red light timing (s)	Current Yellow light timing (s)	Updated Yellow light timing (s)
A to B	40	33	99	85	3	7
G to H	80	70	80	75	3	7
D to I	35	30	99	85	3	7
C to J	35	30	99	85	3	7

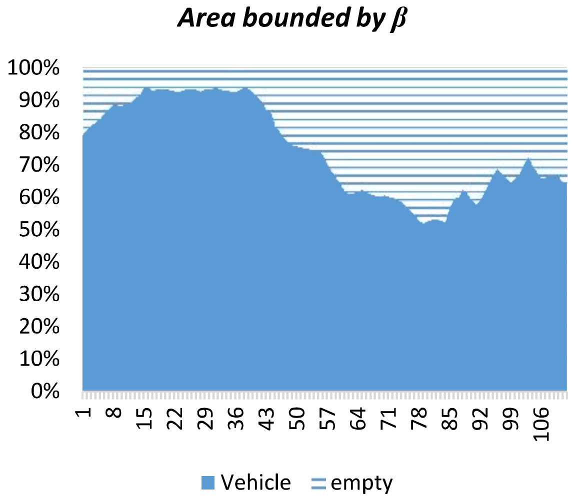

Fig. 10. Monitored vehicle density occupied in the area bounded by β in time duration of 35 seconds.

According to the simulation scenario given in Fig. 6, the system has estimated the unoccupied area on the predefined areas from the input video frames, from which the timing for green and red signals of two-way AB and CD phases will be updated, respectively.

Tab. I shows the estimated update of traffic light timing which is based on evaluation of the road area occupied by the vehicles on different phases. Since the timing is similar for all phases, the other phases also operate in the similar manner to A-B phase. The timing update based on the estimation of the occupied area by vehicles is shown to have superior performance compared to that utilizing estimation of the empty area which was proposed in our previous work [10]. However in this work, the authors estimate the vehicle density only within the area bounded by L, therefore it is lack of information to adjust the timing flexibly compared to the proposed idea. This additional modification can resolve vehicle density estimation of the mixed traffic flow compared to what was implemented in [10] because it is flexible to setup for different roadways, where the camera is only required to mount for the most crowded phase.

4. Conclusion

This paper has proposed an efficient method to estimate the traffic flow based on the vehicle density estimation and analysis of the unoccupied area on the road. The resulting density is then utilized to update the timing control of traffic light signals automatically. This method focuses on the traffic density of vehicles but unoccupied area of the vehicles on the road. The verified performance on experimental results is shown to be promising to resolve the problem of automatic control and monitor traffic flow in the transport context of Vietnam, where a mixed vehicle flow typically exists.

Acknowledgement

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