Video based Adaptive Road Traffic Signaling
Indu S, Varun Nair, Shashwat Jain and Santanu Chaudhury

Abstract—The ability to exert real time, adaptive control, of the transportation process is the core of an intelligent traffic system. We propose a video based adaptive traffic signaling scheme for reducing waiting period of vehicles at road junctions without detecting or tracking vehicles. The traffic signal timing parameters at a given intersection are adjusted automatically as functions of the local traffic conditions. The video sequences recorded at junctions are used for generating Spatial Interest Points (SIP) and Spatio-Temporal Interest Points (STIP). The traffic congestion at the junction is estimated using SIP and STIP. The decision rules are based on a definitive analogy between road traffic and computer data traffic wherein road vehicles are compared with data packets on the network. The system is similar in approach to the technique of Weighted Round Robin (WRR) queuing, a scheduling discipline used in data communication networks. Local traffic information is used to adjust the phase split keeping the cycle time constant. Two methods have been proposed. The first method, Optimal Weight Calculator (OWC), minimizes traffic at an intersection by determining the optimal phase splits or weights. The second method, Fair Weight Calculator (FWC), calculates weights relative to the road with minimum traffic to bring more fairness. After applying the respective algorithms mathematically on varying traffic conditions, OWC was found to be more equitable in the allocation of green time which is suitable for highly weight-sensitive junctions. For traffic with road priorities, FWC was found to be a much faster and effective control strategy.

Keywords—Data communication; traffic; Distributed vision; transportation; Emerging applications

1 INTRODUCTION
Ever increasing number of vehicles on road, high fuel cost and environmental concerns are motivating researchers to come up with intelligent, simple and economical traffic systems. There are two types of conventional traffic lights control system in use. One type of control uses a fixed preset cycle time to change the traffic light. The other type of control is adaptive in nature as it combines preset cycle time with proximity sensors which can activate a change in the cycle time/phase splits/offset. Fixed preset is incapable of handling varying traffic conditions at an intersection. Therefore an adaptive control mechanism is the only solution. Current traffic control techniques involve data acquisition through magnetic loop detectors buried in the road [1], infra-red, proximity sensors and radar sensors which are subject to a high failure rate. Video-based systems provide more traffic information, are easily installed, and are scalable with progress in image processing techniques. Most of the decision making algorithms are based on case reasoning, fuzzy logic, neural networks or multi-agent systems. Authors of [2] and [3] implemented a real time fuzzy logic traffic controller. Selecting an appropriate membership function for roads with unpredictable states is a major challenge/limitation for Fuzzy logic controller. Verma and et. al. [4] developed an ITS using Wireless Sensor network (WSN) installing external hardware both on vehicles and roads which makes it complex and costly. We propose a video based adaptive road traffic light control method motivated by network data traffic control methods. The road traffic junction is considered as a computer data traffic junction where vehicles are considered as data packets. Two methods have been proposed: Optimal Weight Calculator (OWC) and Fair Weight Calculator (FWC). FWC is based on Variably Weighted Round Robin [5] where the weights are assigned according to the maximum value of Traffic State Ratio which ensures fairness in allocation of weights. OWC, based on [6], on the other hand tries to minimize traffic at an intersection by calculating optimal weights subject to certain constraints using linear programming technique.

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2 PROBLEM STATEMENT

2.1 Related work

It has been more than two decades that road traffic monitoring has been motivating researchers. Among many works, we discuss a few due to space limitation. Authors of [7] proposed a Vehicle Information and Communication System (VICS) for travel time prediction and congestion avoidance using numerous ultrasonic and radar detectors installed on roads in addition to employing VICS units in vehicles and infrared beacons. The method needs ultrasonic detectors to be mounted in a down-looking configuration as perpendicular as possible to the target (as opposed to side mounting), identifying lane-straddling vehicles and vehicles traveling side by side, and also susceptible to high wind speeds. Martí et. al [8] presented a rule-based road traffic management system for tackling weather induced problems on the road network. Based on specific logic rules and decision rules which can be added and modified, the inference engine decides to whether send an alarm or not. The system works only within the domain of already created rules and does not involve learning.

2.2 Problem Description

In general traffic signal timings are decided according to the importance of the road. This may increase waiting period of vehicles at the intersection. Figure.1 shows a four way traffic intersection. We propose a video based adaptive traffic signaling method for reducing the waiting period of vehicles at the junction. Video cameras are placed along the road as well as near the junction. Two features are extracted from video sequence: Spatial Interest Points and Spatio-Temporal Interest Points, as shown in Figure.2. Spatial interest points are points in spatial domain with significant variation in local intensities whereas spatio-temporal interest points (STIP) are points in space-time domain with significant variation in local intensities. All the vehicles on a road generate SIP and the moving vehicles generate STIP. Hence, the number of SIP is indicative of number of vehicles on a road and the number of STIP indicates the moving vehicles on the road. It is not possible to count number of cars in real time without involving complex calculations or processing. The ratio of STIP to number of SIP (Traffic State Ratio or TSR) gives an approximation of percentage of moving vehicles, which can be easily calculated in real time. Higher the ratio lesser is the traffic. The local traffic information or the state of the road is measured by the method proposed in [9], which is essentially a video-based traffic prediction algorithm based on Hidden-Markov Model (HMM). In this paper we are proposing a novel traffic control mechanism by modeling a road traffic junction as a queue of a router as shown in Figure.1. The entire traffic cycle is seen as a round robin scheduling event [10] where weights for each route are calculated using the Traffic State Ratio (TSR) in an adaptive manner. In both the methods it is assumed that during the green time the vehicles on a road are allowed to go straight and to other roads as well.

2.3 Optimal Weight Calculator

The Optimal Weight Calculator algorithm is presented for a 4-Road junction shown in Figure. 1. This can be extended for an n-Road junction. Weight $w_i$ is defined as the ratio of green time (i.e. the time for which traffic light is green for a road in a cycle) to the cycle time (i.e. the summation of the green time of all the roads in the junction). In other words it is the fraction of cycle time allotted to a road $i$ as green time.

$$w_i \times T_{cycle} = Green Time$$

(1)
In general, by increasing weight \( (w_i) \) the traffic on the road \( i \) decreases and hence the \( TSR \) increases. Similarly decrease in weight leads to decrease in \( TSR \). In case there is no traffic, \( TSR \) tends to one. The \( TSR \) and weights allotted are assumed to be in linear relation.

\[
TSR = k \ast w + c \tag{2}
\]

here, \( c = 0 \) and \( k \) is the slope. Without the loss of generality, the constant \( c \) is considered zero as it is not depending on the weights and it has no effect on the calculation of the weights.

\[
TSR(w_1, w_2, w_N) = \sum_{i=1}^{N} k_i w_i \tag{3}
\]

The Optimal Weight Calculator minimizes the total waiting time of vehicles or total number of vehicles stopped in a cycle time at the junction by maximizing the total \( TSR \) as shown in Equation.4.

\[
\text{Maximize } \sum_{i=1}^{N} k_i w_i \tag{4}
\]

Subject to constraints:-

\[
W_{\text{thresh}} + y_i \leq w_i \leq 1 \tag{5}
\]

\[
\sum_{i=1}^{N} w_i = 1 \tag{6}
\]

Where, \( W_{\text{thresh}} \) = threshold or worst case weight and

\[
y_i = \frac{k_i(\text{current}) - k_i(\text{prev})}{r_i(\text{prev})} \tag{7}
\]

where \( r_i \) - average \( TSR \) for the \( i_{th} \) road for previous 1 cycle.

To incorporate the dynamic nature of traffic, the slope \( k \) associated with Equation.2 is calculated for every upcoming cycle using the \( TSR \) and weight values of the current and previous cycles.

\[
k_i(\text{next}) = \text{abs} \left| \frac{r_i(\text{current}) - r_i(\text{prev})}{w_i(\text{current})} \right| \tag{8}
\]

The quantity \( y_i \) in Equation.5 is introduced to account for sudden changes in the traffic pattern and at the same time keep the calculated weight values in accordance with the current traffic pattern. Equations 4, 5 and 6 represent a typical linear programming formulation which gives us the required optimal weight values. The proposed method is computationally light and independent of the number of roads entering a junction.

### 2.4 Fair weight Calculator

[5] proposes a lightweight, simple QoS / CoS control method called VWRR (Variably Weighted Round Robin) for use on high-speed backbone networks. This method provides greater fairness in terms of resource sharing among all kinds of traffic classes, for a given processing load, than other round-robin methods. We applied the same in Road Traffic. In this case a proportionate weight with respect to minimum traffic road is calculated for each road by Equation.9. Hence for a large value of \( r_i \) we get proportionately smaller value of \( w_i \) which in turn reduces the green time period. For avoiding negligibly small \textit{green time} we assign a minimum weight \( W_{\text{ifnl}} \) as given bt Equation.12 Let \( M \) be the maximum value of average \( TSR \) of all roads.

The proportionate weight is then calculated as

\[
W_i = \frac{M}{r_i} \quad i = 1, 2, ..N \tag{9}
\]

The value of \( W_i \) can be normalized to vary in the range \([0 \text{ to } 1]\), by normalizing Equation.9

\[
W_i(\text{norm}) = \frac{W_i}{S} \quad i = 1, 2, \ldots, N \tag{10}
\]

where

\[
S = \sum_{i=1}^{N} W_i \tag{11}
\]

If \( W_i(\text{norm}) < W_{\text{min}} \), minimum weight assigned

\[
W_{\text{ifnl}} = W_{\text{min}} + (1 - N \ast W_{\text{min}}) \ast W_i(\text{norm}) \quad i = 1, 2, \ldots, N \tag{12}
\]

In case of clear traffic in all the roads, the corresponding weights assigned will be equal and for heavy traffic, maximum weight is assigned to the corresponding road. The maximum weight and the weights for the rest of the road vary dynamically with the change in traffic over the course of time.
### TABLE 1
Green Timings for Scenario-I

<table>
<thead>
<tr>
<th>Road</th>
<th>State of Road (TSR)</th>
<th>Green Time (sec) Normal</th>
<th>Green Time (sec) OWC</th>
<th>Green Time (sec) FWC</th>
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<tbody>
<tr>
<td>Road N</td>
<td>Heavy (0.2432)</td>
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<tr>
<td>Road E</td>
<td>Mild (0.5605)</td>
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<tr>
<td>Road W</td>
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<td>Road S</td>
<td>Heavy (0.2393)</td>
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### TABLE 2
Green Timings for Junction shown in Figure.4

<table>
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<th>Road</th>
<th>State of Road (TSR)</th>
<th>Green Time (sec) Normal</th>
<th>Green Time (sec) OWC</th>
<th>Green Time (sec) FWC</th>
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<td>Road S</td>
<td>Heavy (0.2123)</td>
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### 3 RESULTS AND DISCUSSION

#### 3.1 Simulation

We used Synchro Studio 8 to simulate two different traffic scenarios and compare the green timings assigned by the OWC and the FWC with the conventional traffic signal timings (fixed green times). The results are shown in Table.1. The video frame in Figure.3 shows the first traffic scenario. SIPs and STIPs were generated, using the current frame and the 5th succeeding frame. Further, green time is calculated assuming the cycle time to be 250 seconds.

Figure.4 shows the second scenario. The state of road ‘S’ is heavy and other roads are open. The weights for normal or non-adaptive method are still the same for all the roads while in OWC and FWC the weights have changed adaptively and become higher for the more congested road and lower for the less congested road as shown in Table.2.

The results shown in Table. 1 and Table 2 indicate that both the proposed adaptive methods fare better in comparison to conventional traffic signaling. Only a single cycle readings have been shown here since the traffic pattern in the simulation remained the same throughout the simulation time. The relative difference in the weights is higher for FWC than for OWC. This is indicative of the fact that the former is more prioritative towards the road with maximum traffic.

#### 3.2 Experimental Evaluation

We applied the said algorithms on an actual traffic scenario- a 4-way road junction. 4 separate cameras were placed at the junction (Figure.5) that recorded traffic for a period of 2 hours on 2 different days. SIPs and STIPs were generated from each of the recordings and average values of the TSR were calculated per traffic cycle. One traffic cycle lasted for approximately 250 seconds.

The tables.3,4,5 and 6 show the day-wise green timings calculated for each of the 4 roads for 5 traffic cycles by both the methods. The TSR values from Table.3 show traffic in Road 3 to be relatively heavier as compared to the other roads. This is consistent with the values obtained for Day 2 (Tables.4 and 6) as well. The green timings, as one would
expect, are also significantly higher for Road 3 for both OWC and FWC. The distinctive feature in the results of the two methods is the value of green time assigned to the road with maximum traffic. Tables 3 and 5 show that the FWC has a tendency to allocate a higher weightage to the road with maximum traffic than the OWC. The OWC tends to be more equitable in its allocation especially when there is lesser relative difference in the TSR values of the roads.

Figure.6 depicts the plot of the $TSR$ for 4 roads (simulated values) at an intersection and the corresponding distribution of weights for the respective roads calculated by the Optimum Weight Calculator algorithm. Each road is in a particular traffic state (Open, Mild, Heavy or Stop). This is desirable since allotting a higher green time to the stopped road will help to reduce traffic in the road over time. The figure clearly shows that the weight assigned to a stopped road is high and that of an open road is very low. Thus the OWC method attempts to minimize the traffic at the junction.

Figure.7 depicts the $TSR$ (simulated values) and Weight plot calculated by Fair Weight Calculator. Here we have considered a mixed traffic distribution in the 4 roads. As can be inferred from the graph and Equation.10, this method gives priority to the more congested road during the allocation of weights. Higher the $TSR$, Lower will be the weight and vice versa. At all times during the observation period, the road with the highest $TSR$ is given the maximum green time. But this maximum value is determined taking into consideration the dynamic traffic condition of the other roads. So if traffic in any other road(s) begins to build up, this maximum value will decrease over time. This is where the algorithm achieves fairness.

4 CONCLUSION

This paper has presented a video based adaptive time sharing model for road traffic management. The two proposed methods have different approaches but the essential idea is the same i.e. to minimize the waiting period of vehicles at the junction. In our findings FWC prioritize road states and allocate green time in comparison to OWC which in turn was found to be more equitable in the allocation of green time. The results have demonstrated that the model guarantees dynamic time allotment for different traffic characteristics. Besides, it is worth
noticing that the developed model can be applied universally on multi road junctions irrespective of number of roads.

REFERENCES


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<th>TSR Cycle 4</th>
<th>TSR Cycle 5</th>
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TABLE 3
Green Timings for Each Road shown in Figure. (5) calculated by OWC (Day 1)

<table>
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<tr>
<th>Road</th>
<th>TSR Cycle 1</th>
<th>TSR Cycle 2</th>
<th>TSR Cycle 3</th>
<th>TSR Cycle 4</th>
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<th>Fixed time</th>
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TABLE 4
Green Timings for Each Road shown in Figure. (5) calculated by OWC (Day 2)

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<th>TSR Cycle 2</th>
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TABLE 5
Green Timings for Each Road shown in Figure. (5) calculated by FWC (Day 1)

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TABLE 6
Green Timings for Each Road shown in Figure. (5) calculated by FWC (Day 2)