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Real-time Traffic Control for Urban City Intersections

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Abstract— Traffic congestion on public roads is an increasing problem. It plays an important role in degrading the quality of life, results in lost fuel, time and drops the air quality of the region. When we consider developing countries, increasing the infrastructure to accommodate the rapidly growing number of cars that hit the road everyday isn't a viable option. The solution might lie in the way we manage the traffic on our roads. An ideal traffic signal can reduce traffic using several techniques. This paper revolves around adaptive traffic control designed specifically for an urban environment which works on signalized roads and intersection Taking aid from the advancements in the field of image recognition to gather real-time data about the flow of cars and pedestrians at the intersection, we give a theoretical approach to solving the problem in an urban scenario. The model obtained is used to predict the traffic flow and adapt for situations in real-time. The objective is to reduce the time a vehicle spends at an intersection by operating the traffic signals dynamically. While doing so, the algorithm also accommodates the pedestrians wishing to cross the street.

Index Terms— Adaptive traffic control, artificial intelligence, image recognition, intelligent transportation systems, machine learning, optimization, real-time systems, urban traffic systems

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1 INTRODUCTION

Humans tend to drive at different speeds and change lanes as per our requirement. This makes the problem of handling traffic at an intersection computationally intractable. Poor traffic signal timing contributes to traffic congestion and delay. There are plenty of formulas recommended by various agencies and journals [10] which may be used to derive the time durations for a traffic signal i.e. the time period for which the traffic light stays in a particular state.

Classical control systems [1], [9] which are conventionally used to control the flow of traffic through an intersection rely purely on the historic data of traffic flow through the intersection for a predefined time period. Thus, these methods fail to take into account the variations in the vehicular flow in real time making the system rigid and, thus, not a good fit if we want a real-time solution to the problem of urban traffic control.

For a more fluid approach we shall shift our attention to the field of artificial intelligence and machine learning. Image recognition has been rapidly growing as a field of research over the past decade. Recent advancements in this field provides access to tools which enable high-precision processing of videos [4]. This opens the gateway for tracking and identifying multiple moving objects such as vehicles [4] and pedestrians in real time [3]. Building on this technology, we can track the vehicles entering and leaving an intersection [4] as well as approaching or waiting pedestrians. Image recognition is not the only technology we can rely on. Various sensing devices such as RF sensors, ultrasonic sensors, pneumatic tubes, pressure sensors or wireless sensor networks can also be deployed to accomplish the same [6]. However, this will require additional financial resources and man-hours. Thus a technique using video cameras which may also be used for surveillance is a better investment.

Several approaches based on artificial intelligence have also been suggested. One approach based on supervised learning from human performance [11]. In this approach, a user essentially plays a game on a simulator. The human controls the traffic signals and is given the objective to maximize the number of vehicles crossing the intersection over a fixed period of time. The data obtained from this process of human interaction with the simulator is used to train a model. A problem with this approach is scalability i.e. when we consider a multi-nodal system.

As pointed out earlier, our approach to real-time traffic control is based on the recent work in the fields of real-time urban traffic control [7] and advancements in image recognition [3], [4]. Prior to moving on to our proposed work, we first summarize the underlying concept of adaptive traffic control [5], [6].

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2 ADAPTIVE TRAFFIC CONTROL

Adaptive traffic control [5], [6] is an approach which caters to the dynamic nature of traffic. The concept of adaptive traffic control is based on the detecting flow of traffic through a network of intersections. This information is taken for both an upstream point and a downstream point. The deployed algorithm then predicts the movement of the traffic and attempts to make adjustments in the signal timings at the intersection on the downstream intersection with respect to the movement of the traffic based on the algorithm's prediction. The algorithm is deployed on a module called the *signal controller* [5]. The signal controller computes optimal timings for the signals at the intersection. The decisions are based on the traffic approaching the intersection (or at the intersection) are implemented in real-time. Since the decisions are being made in real time, this allows the system to adjust and adapt for the variations in the flow of traffic over time. The goal here is to reduce the delay for pedestrians and vehicles which results in shorter queues, decreased travel time and higher throughput at the intersections [5]. By adjusting the traffic signals and control parameters dynamically through an autonomous signal controller, the system has the potential to improve travel times, increase the average speeds of the vehicles on roads and reduce the traffic delay due to clogged intersections [6]. This gives it an edge over the other conventional methods described earlier making it ideal to be used as a foundation for paper.

3 PROBLEM DEFINITION AND PARAMETERS

In this paper, we focus on urban city intersections which have traffic signals installed i.e. signalized intersections. A cycle of each signal (for each lane l) on the intersection switching to green is called a *phase* (p). In each phase, vehicles may arrive at the intersection from all directions and wait for the green signal which allows them to pass through the intersection. The lanes connected to the intersection are given as a set S = $\{l_1, l_2, \ldots, l_n\}$ where n is the number of lanes meeting at the intersection. A vehicle waiting at the intersection is free to choose any lane from the set S once the signal is green. Another set P (subset of S) holds the lanes which have not been signaled green in phase p. At the beginning of each phase, P has all the lanes as an element in it. We define some constraints which aid the functioning of our signal controller. In a phase, the time for which the signal switched to green is between $\partial_{\max}(p)$ and $\partial_{\min}(p)$, where $\partial_{\max}(p)$ and $\partial_{\min}(p)$ are the maximum and minimum times respectively for which the signal indicates green on a given lane on the intersection. The time taken by a pedestrian to cross one lane/side of the intersection safely is given by U_P. For each signal on the intersection, the time for which the signal runs yellow in a phase is predefined and set constant to a time duration of Y_C. At any instance, the green time remaining for a signal is given by $\partial_r(p)$.

It is assumed that the vehicular inflow/outflow and pedestrians approaching the intersection can be monitored in real-time using cameras, radars, ultrasonic sensors and other necessary equipment [3]. The vehicles or pedestrians approaching the intersection or the pedestrians waiting to cross the intersection cannot explicitly signal their presence to the system. Time delay is the time spent by a vehicle crossing the intersection.

Thus, the problem of interest is to minimize the time delay for both the vehicles and the pedestrians by dynamically generating the timings for the signals and manipulating the green time of the signals in each phase.

4 PROPOSED WORK

4.1 Control parameters

As a control, we need to know the number of cars which can cross the intersection for a given lane and phase in time $\partial_{\max}(p)$. This can be estimated by the length of the queue of cars that are able to clear the intersection in $\partial_{\max}(p)$ time. We call this maximum queue length (Q_{max}) as shown in figure 1. We also need to know the inflow ($I_{(p,l)}$) and outflow ($O_{(p,l)}$) of vehicles in real-time to synchronize and optimize the flow of traffic through multiple intersections. Inflow is the number of vehicle entering the intersection in a given phase and outflow is the number of vehicles crossing the intersection in a given phase. Both these quantities are different for each lane constituting the intersection. A threshold value ($\Delta_{(p,l)}$) defines the maximum inflow a neighboring intersection can handle without causing congestion. Thus, for a given phase on an intersection we have the tuple $<p, I_p, O_p>$ indicating the phase, the inflow in that phase and the outflow in that phase which is used while communicating with other intersections (nodes).

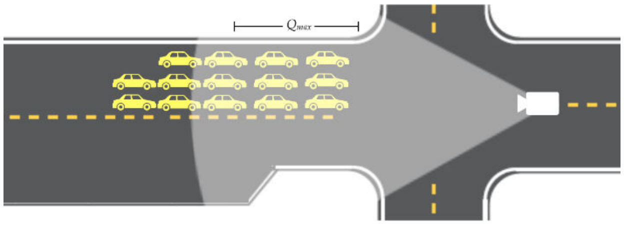

Fig. 1 The maximum queue length Q_{max}

In a network with multiple intersections on which the system is functional a basic protocol is followed. This protocol dictates that each intersection sends its outflow data $O_{(p,l)}$ for each lane l in phase p to its neighbour. This information constitutes the inflow data removing the need for the system on the next node to calculate the numbers of vehicles approaching the intersection and saving computational resources. The outflow information is only sent to the intersection for which it conveys the inflow and not to every neighboring intersection. The intersection which sends the information is the upstream intersection [5] and the intersection which receives the information is the downstream intersection [5]. Another vital piece of information sent to the neighbors is a *distress flag*. This flag carries two values: 1) source location and 2) flag status. The source location conveys the origin of the flag and the flag status is may be set HIGH or LOW. If the flag is HIGH, the system is said to be in distress.

4.2 Single intersection

In a phase, all signals are activated at least once under normal circumstances. This is done in either a clockwise manner. Throughout the operation the system has access to a memory database which stores four values: 1) the time at which the reading was recorded, 2) the lane l for which it was recorded, 3) the outflow from that lane in that phase $O_{p,l}$ and 4) the time for which the signal is set to green $\partial(p)$. These values are saved as a hash table.

A green signal for a lane l is not preempted unless: 1) there is no vehicle waiting in lane l and 2) there are no pedestrians waiting to cross the intersection on the opposite side. If both the conditions are true, then the green signal for that lane is skipped making $\partial_{\min}(p)=0$. However, if is a pedestrian waiting on the other side who will not be able to cross the intersection if the next signal turns green for time $U_{\boldsymbol{P}}$, thus $\partial_{\min}(p)=U_{\boldsymbol{P}}$. This implies, $\partial_{\min}(p)\in\{0, U_P\}$.

As the vehicles approach the intersection, they wait for the intersection to signal them with a green, allowing them to pass through. We monitor the length of the queue formed by the cars in a lane when the signal is red. If the length of the queue (L) is greater than Q_{max}, then the duration of the green signal for the next phase is set to $\partial_{\max}(p)$. The number of vehicle leaving the crossing the intersection from lane l in phase p is given by $O_{\max(p,l)}$

Initially, we assume that the relation between $O_{(p,l)}$ and $\partial(p)$ is linear. This indicates that if $O_{max(p,l)}$ vehicles leave the intersection in time $\partial_{\max}(p)$, then $(O_{\max(p,l)})/2$ vehicles will be able to cross the intersection in time $(\partial_{\max}(p))/2$. The system initially runs on this assumption. For a given length L in a phase, it refers the hash table for lane l searching for a corresponding reading. If no historic reading is not found, a new record is initialized and the system calculates the value for $\partial(p)$ based on the value of $I_{(p,l)}$, $O_{(p,l)}$ and $\partial_{\max}(p)$ and is given as described in (1):

$$\partial(p) = \begin{cases} \partial_{\max}(p) & ; L \geq Q_{\max} \\ (I_{(p,l)} * \partial_{\max}(p))/Q_{\max} & ; L < Q_{\max} \end{cases} \tag{1}$$

This is referred to as *cold start* as described in [8]. The calculated value is saved in the hash table. The system tracks the departure of the last/farthest vehicle which was standing still when the signal was red i.e. when the calculation for $\partial(p)$ was performed. If the vehicle crosses the intersection before the predicted time runs out, the algorithm decrements the corresponding value in the hash table to the actual time it took the vehicle to cross the intersection. However, if the vehicle is unable to pass the intersection in the predicted time, the algorithm increments the corresponding value to the actual time it took the vehicle to cross. With sufficient readings based on real scenarios, the system can move shift its dependency on calculations to referring the hash table. It is to be noted that these calculations are made in the Y_C time when the signal of the previous lane turns yellow. The green signal duration is always between 0 and $\partial_{max}(p)$ thus $\partial(p)\in\{0, \partial_{max}(p)\}$.

Throughout its operation, the system keeps recording the tuple $<p, I_p, O_p>$ described earlier with a timestamp. This information is used to predict the movement of traffic.

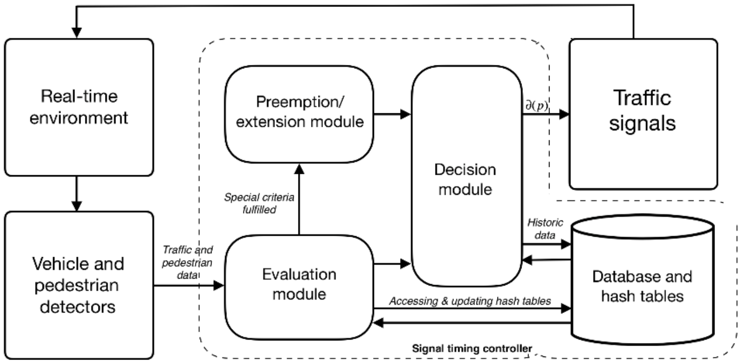

Fig. 2 Block diagram of the system

4.3 Special cases

These cases describe approaches when the system detects a particular condition. These describe changes in the system's normal functionality under certain circumstances. Before considering these scenarios, we familiarize ourselves with two terms: signal preemption [5] and signal extension [5]. Signal preemption refers to the act of breaking the normal sequences of a phase in which the signals where to be operated and switching to green a particular signal on the intersection. Signal extension means extending the duration for which a signal which is already green stays green.

4.3.1 Accommodating pedestrians

Since the pedestrians cannot explicitly indicate their arrival to the system, we must use the equipment installed at the intersection to signal the system when the first pedestrian arrives at the crossing. We are not concerned with the number of pedestrians waiting on a particular side of the intersection as the pedestrians walk in a cluster and not in a lane.

Since the flow of pedestrians is bidirectional in nature, it is best suited if they cross the street in a single stage. As discussed earlier, if the system recognizes a pedestrian waiting to cross the intersection, the system gives them a time of U_P to cross the intersection safely regardless of the traffic on the corresponding lane. This ensures that the waiting time for a pedestrian is never more than $(l-1) * \partial_{\max}(p)$.

Alternatively, to offer higher priority to the pedestrians, we could set a maximum limit on the waiting time [7] for the pedestrians. PW_{max} is used to indicate the maximum time a pedestrian would have to wait in this scenario. As soon as the first pedestrian arrives at the intersection, the system checks the relation between the difference between ∂_r(p) and PWmax. If the difference is greater than a predefine threshold H, the green signal is preempted to allow safe passage for the pedestrians. This essentially splits the green signal into two parts. Once the pedestrians cross, the green signal is resumed for the lane. If the difference is less than the threshold, the pedestrians wait for the signal to turn red. The threshold H ensures that the vehicles don't stop for a small duration which overall hurts the cumulative delay. For example, the vehicles coming to a halt for a period of 10 seconds while the pedestrians cross before they get a green signal again for 4 seconds.

4.3.2 Approaching emergency vehicles

Quick passage for an emergency vehicle is of high priority. When an emergency vehicle approaching the intersection is detected, the system judges the queue length L for the emergency vehicle as shown in the figure 3. If L is less than $Q_{\max}$, the algorithm calculates $\partial(p)$ for the signal. The system preempts the current cycle of the phase giving passage to the emergency vehicle. If L is more that $Q_{\max}$, the algorithm simply keeps the signal green till one of the two things happens: 1) the emergency vehicle passes the intersection safely or 2) the outflow from that lane exceeds the threshold value $\Delta_{(p,l)}$. The intersection indicates the downstream node by setting the distress flag to HIGH.

Fig. 3. Approaching emergency vehicles.

4.3.3 Outflow to non-signalized intersections

The intersection might have lanes which lead to intersections which might not be equipped with a similar system. In such a scenario, we can only correct for excessive congestion on the lane by managing the outflow to towards that lane. In a situation where the lane seems to be clogged and overflowing with vehicles, as shown in figure 4, the system goes in a state of distress.

The system preempts the normal signal cycle for that phase, a new phase is started and calculates $\partial(p)$ for its adjacent side. If $\partial(p) = \partial\max(p)$, then the signal turns green. After a duration of $\partial(p)$, if the congestion still exists, the system searches for the another lane in set P with the least predicted outflow towards the congested lane based on the historic data and calculates the $\partial(p)$ for that lane signaling a green for that lane. If the situation still persists, the system repeats the same process even if it goes into a new phase. If, however, $\partial(p) < \partial\max(p)$, the system simply looks for the system searches for a lane in set P with the least predicted outflow towards the congested lane based on the historic data and allows the vehicles to pass through.

Fig. 4. Clogged/overflowing lane.

4 CONCLUSION

As the number of vehicles on the roads increases rapidly, the challenge of keeping up with the growing demand is exhausting. In this paper, we have described a logical extension to the approach of adaptive traffic control which is uses minimal resources, takes into account the dynamic nature of vehicular flow and exploits the power of image recognition to build a system which is equipped to manipulate traffic signals in real-time. The system has the potential to decrease the travel delay at intersections with a varying traffic flow through the day. The paper provides a decentralized approach which takes into account pedestrians, emergency vehicles and congestion and doesn't fall short if the neighboring intersections aren't equipped with the same system.

There are several aspects of this work that warrant further study. First, a system built to better cater the pedestrians might be more suitable for certain areas. Second, the system might be improved to accept signals or messages from approaching vehicles or pedestrians with high priority prior to their arrival at the intersection.

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