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Constrained Dynamic Control of Traffic Junctions

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Abstract

Excessive traffic in our urban environments has detrimental effects on our health, economy and standard of living. To mitigate this problem, an adaptive traffic lights signalling scheme is developed and tested in this paper. This scheme is based on a state space representation of traffic dynamics, controlled via a dynamic programme. To minimise implementation costs, only one loop detector is assumed at each link. The comparative advantages of the proposed system over optimal fixed time control are highlighted through an example. Results will demonstrate the flexibility of the system when applied to different junctions. Monte Carlo runs of the developed scheme highlight the consistency and repeatability of these results.

Keywords: traffic junction model; state space modelling; adaptive traffic light control; dynamic programming.

1. Introduction

Modern urban areas are witnessing increasing traffic congestion due to high car ownership rates and a strong dependency on private cars. Junctions often pose the main bottleneck in urban traffic networks resulting in capacity flow on the network links and excessive delays. A continuous expansion of the infrastructure cannot remain the go-to solution to these problems due to land-use, environmental and financial limitations. An alternative is the use of dynamic traffic control strategies that are adaptable to prevailing traffic conditions. Such methods can provide a safe and feasible solution to traffic congestion problems through the efficient and intelligent use of the network.

Various types of adaptive control systems have already been implemented and have shown promising results. Two such widely used systems are SCOOT[1] and SCATS[2]. These systems use real time measurements to dynamically effect the split time, offsets and cycle time according to current traffic conditions. These commercially available systems are known to be very well optimised for under-saturated traffic conditions, however, their performance tends to deteriorate in heavy traffic[3]. Other widely used control systems including OPAC[4], PRODYN[5] and RHODES[6], implement model-based optimization and thus use current traffic measurements to identify in real-time an optimal control strategy.

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The last two decades also saw the introduction of the TUC system[7]. This system is based on the store-and-forward model as proposed by Gazis and Potts[8], where a multivariable linear regulator approach is used to optimize in real-time the network splits. The closed form solution obtained makes this system ideal for real time implementation, however such an approach cannot handle constraints and hence requires a final tuning procedure. Nevertheless, TUC has been successfully implemented in various places including Greece[9]. More recently, Tettamani *et al.*[10] proposed a traffic control system based on model predictive control. Other computationally expensive numerical solutions have also been proposed including genetically tuned controllers[11].

The work in this paper aims to provide a competing real-time adaptive control strategy which through the use of dynamic programming can natively handle the nonlinear constraints involved in the control of the traffic at a junction. This method is based on a novel model of traffic dynamics recently proposed by Pecherkova *et al.*[12]. Similarly to the store-and-forward models, this model can easily be extended to accommodate multiple junctions with any configuration. The implementation is kept flexible by allowing the use of different cost functions and most importantly, different detector configurations. It will be shown that through the use of Kalman filtering, the degradation in performance at the junction is only minimal if less sensors are used, thus allowing for a robust and cost-effective implementation.

This paper is divided into 4 Sections. Section 2 presents the model description of the traffic system used in this work and the development of the dynamic controller being proposed. In Section 3, an implementation of the dynamic controller at a junction is presented together with a discussion of the results obtained. Finally, Section 4 highlights the main results and draws some concluding remarks.

2. State Space Junction Modelling and Control

The state space model of a junction used in this work is based on the model proposed by Pecherkova *et al.*[12] which uses realistic non-linear dynamics to represent traffic flow. The traffic flow through a controlled intersection can be described by the following quantities with k being the cycle index:

- Queue length (ζ_k) is the number of cars queueing at a link to pass through the intersection at the start of each cycle (in unit vehicles [uv])
- Intensity (I_k) is the rate of incoming unit vehicles per cycle (in uv/period)
- Occupancy (O_k) is the portion of time during which the detector is occupied by a vehicle (in %)

Note that the cycle time can be set to any reasonable value by the user. Considering a single arm of the intersection, the queue length is described by the principle of conservation[13], where the queue during the next timing period ζ_{k+1} depends on the previous queue ζ_k, the incoming intensity I_k and the outgoing intensity I_k^π, through the relationship:

$$\zeta_{k+1} = \zeta_k + I_k - I_k^\pi(\zeta_k, I_k, z_k) + w_{1,k} \quad (1)$$

where the intensity of outgoing vehicles is given by the non-linear relationship:

$$I_k^\pi(\zeta_k, I_k, z_k) = S - S\,e^{-\frac{\zeta_k + I_k}{S z_k}} \quad (2)$$

with

- S being the saturated flow determined by the physical properties of the intersection,
- z_k being the ratio of green time per cycle and
- $w_{1,k}$ being a white, zero-mean, Gaussian noise process describing the random variations from this mean behaviour.