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Automated tuning of ITS management and control systems: Results from real-life experiments

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ABSTRACT

The design and deployment of the majority of Management and Control Systems (MCS) for ITS involves a tedious, effort- and time-consuming manual tuning and calibration procedure not only during the initial design and deployment of the ITS but, in most cases, during its whole lifetime. Recently, we have developed and evaluated, both by means of theoretical analysis and extensive simulation experiments, a new methodology which fully automatically takes over the manual tuning and calibration procedure. Most importantly, this new methodology, called Adaptive Fine-Tuning (AFT), achieves to improve the performance of the system and compensate the effect of the continuous changes of its behavior that may be due to either internal or external factors. In this paper, we report results of implementing AFT to a real-life ITS MCS. More precisely, this paper reports and analyzes the results from implementing AFT to an urban traffic signal control application. The results from AFT real-life application demonstrate that it is capable of significantly improving the performance of the system in a safe and robust manner. Moreover, the real-life results exhibit the capability of AFT to efficiently adapt and compensate in cases of changes in the system behavior, even if these changes are significant.

1. Introduction

Despite the continuous and very impressive advances in the fields of information and communication technologies, the design and deployment of efficient Management and Control Systems (MCS) for ITS (Intelligent Transportation Systems) remains a challenge. The complexity of the ITS dynamics and interactions, the frequent ITS infrastructure minor or major changes and – most importantly – the highly stochastic user behavior render the problem of designing and deploying an efficient MCS a challenging task. To cope with this problem, the design and deployment of the majority of MCS for ITS involve a tedious, effort- and time-consuming manual tuning and calibration procedure, not only during the initial design and deployment of the ITS but, in most cases, during the whole lifetime of the ITS. Typically, such a tuning and calibration procedure involves teams of highly experienced personnel that tune and calibrate the system based on heuristic, experience-based rules. Apparently, such a human involvement, apart from being costly, does not provide any guarantee that the overall tuning/calibration procedure will be successful.

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Recently, we have introduced and analyzed, both mathematically and by means of extensive simulation experiments (Kosmatopoulos et al., 2007; Kosmatopoulos, 2009; Kosmatopoulos and Kouvelas, 2009; Kouvelas et al., 2011), a new approach that can fully automatically take over the human-based tuning/calibration procedure. More precisely, a computationally efficient procedure has been proposed, which can be used to automatically tune/calibrate the MCS in an efficient and, equally importantly, safe and robust manner. Both theoretical analysis as well as simulation experiments using quite complex and large-scale realistic traffic/transport models have exhibited that the proposed approach – abbreviated as Adaptive Fine-Tuning (AFT) – not only achieves to optimize the overall performance of the MCS after a relatively short period of its application, but also:

– guarantees that it tunes the overall ITS in a safe manner, i.e., it guarantees that the tuning decisions it makes will not lead the ITS to a poor or unacceptable performance (a typical situation arising in human-based tuning);
– efficiently compensates and adapts, in cases of minor or even major changes of the ITS behavior, that can be either due to changes in the ITS infrastructure or due to the user behavior (including changes of traffic demand patterns).

Of course, the mathematical analysis and the simulation experiments are necessary but not sufficient for exhibiting the efficiency and possible other beneficial (or critical) properties of the AFT approach. Experiments and implementation of AFT to *real-life, large-scale* ITS are also required. Real-life, large-scale ITS include a number of partly unpredictable phenomena, such as sen sor/communication/controller failures, peculiar demand and environmental changes, atypical operation phases and, most importantly, end-user stochastic behavior, that are likely to challenge the attempt to ensure a reliable and efficient operation under all practical conditions.

In this paper, we report results of implementing AFT to a real-life ITS MCS. More precisely, this paper reports and analyzes the results from implementing AFT to an urban traffic signal control application. Section 2 presents a brief overview of the AFT methodology, while Section 3 presents a brief overview of urban traffic control strategies focusing on the one used in this field test. The test traffic network is described in Section 4, and the set-up of the related experiments is discussed in Section 5. The results of this life tests are presented and discussed extensively in Section 7, while the related conclusions are given in Section 8.

2. Automated fine-tuning of ITS: Methodology

The AFT algorithm (Kosmatopoulos et al., 2007; Kosmatopoulos, 2009; Kosmatopoulos and Kouvelas, 2009; Kouvelas et al., 2011) was conceived by enhancing standard stochastic approximation algorithms (Robbins and Monro, 1951; Kiefer and Wolfowitz, 1952; Ermoliev, 1969) and their recent revisions (Spall, 1992), with Cognitive and Adaptive Optimization (CAO) principles (see also Renzaglia et al., 2012). It must be emphasized that, mathematically speaking, automated fine-tuning of MCS of ITS is equivalent to an optimization problem for which an analytical form of the objective function to be optimized is not available, but the value of the objective function for each particular choice of the tunable parameters is available for measurement. As the analytic form of the objective function is not available, it is not possible to either calculate analytically the optimum of the objective function or to apply standard optimization algorithms such as the gradient descent. Instead, the so-called stochastic approximation algorithms are applicable (Robbins and Monro, 1951; Kiefer and Wolfowitz, 1952; Ermoliev, 1969; Spall, 1992) which approximate the gradient of the objective function using its past measured values. Application of stochastic approximation algorithms have been reported for the calibration of traffic simulators or DTA models (Lu et al., 2015) as well as for the automated fine-tuning of ITS MCS (Koch et al., 1997; Ma et al., 2007; Chin and Smith, 1994), using simulation models. Despite their successful application, the fact that they are based on simplistic approximation rules for estimating/approximating the gradient of the objective function, renders them inefficient when it comes to complex ITS (Kosmatopoulos et al., 2007; Kosmatopoulos, 2009; Kosmatopoulos and Kouvelas, 2009; Kouvelas et al., 2011), such as complex urban traffic control systems, and ITS for motorway flow control. To overcome this shortcoming, the authors have developed and proposed AFT which, contrary to the standard stochastic approximation schemes (Robbins and Monro, 1951; Kiefer and Wolfowitz, 1952; Ermoliev, 1969; Spall, 1992), employ an elaborate, yet computationally simple scheme for coming up with an estimation/approximation of the analytic form of the objective function. The combination of such an elaborate estimation/approximation scheme together with the use of randomly generated candidate perturbations guarantees the efficiency of AFT as it was shown both by rigorous mathematical analysis and with extensive simulation studies.

The AFT functioning for the automated fine-tuning of MCS of ITS, can be summarized as follows:

– The ITS dynamics (e.g., the signaling in an urban network) is controlled in real time by a traffic-responsive MCS (of any kind) which includes a number of tunable parameters. Let θ denote the vector of these tunable parameters.
– At the end of appropriately defined periods (e.g., at the end of each day) and given the vector of tunable parameters θ applied on that period, the AFT algorithm receives the value of the real (measured) performance index (e.g., average speed over space and time for traffic networks) for this particular period. Let $J(\theta)$ denote the measured value of the performance index for a given θ. Note that the performance index $J(\theta)$ is a (generally unknown) function of the tunable parameters θ; moreover, $J(\theta)$ is a stochastic function as it depends on various external factors (e.g., traffic demand).
– Using the measured performance, the AFT algorithm estimates the gradient of $J(\theta)$ and calculates a new vector of tunable parameter values to be applied at the next period (e.g., the next day) in an attempt to improve the system performance.