An Alternate Online Calibration approach for O-D demand Calibration in Dynamic Traffic Assignment Systems

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Introduction

The online calibration of Origin–Destination (OD) demand for dynamic traffic systems is a very challenging problem due to its complexity and computational needs [1]. Its goal is to map the simulated traffic measurement towards the observed traffic measurement by identifying the optimal values for the model inputs and parameters (in this context, OD demands). The complexity of OD demand calibration stems from the non–linearity of the dynamic traffic systems, as well as the high degree of indeterminacy of the problem formulation and the lack of observability, in most practical applications. DTA models consist of numerous traffic modelling components, which are denoted as an aggregation of non–linear equations. The relationship between the model parameters and the simulation output is highly non–linear. On the other hand, as the dimensionality of the problem size increases, the model gets more complex. There would be more variables that need to be calibrated, thus leading to very high computational effort in form of both cost and time.

The literature shows that several approaches for online OD demand calibration have been developed in the past decade, such as the Extended, Limiting Extended, and Unscented Kalman filters [2]. More recently the concept of principal component analysis [4] has been introduced in the problem formulation, to reduce the dimensionality. For example, first Principle Component Analysis (PCA) was used with colored Kalman Filter [3], while later, Principal Component–General Least Square (PC-GLS) [6], and Principal Component–Extended Kalman filter (PC-EKF) [5] algorithms were developed and validated for online OD calibration.

In this research, we propose a new algorithm, called Principal Component–Simultaneous Perturbation Stochastic Approximation (PC–SPSA) and apply it to online OD demand calibration for DTA model systems. This approach takes advantages of principal component technique [4] to drastically reduce the dimensionality of the calibrated variables, as well as the highly efficient searching mechanism of SPSA [7]. The proposed approach significantly improves the quality of online calibration and reduces the computational cost.

Methodology

In order to evaluate the performance of PC–SPSA, a comparison between SPSA and PC–SPSA is performed through an extensive synthetic case study, using a number of networks of varying sizes. This setup has the advantage that it allows us to control some parameters, such as the non–linearity, as well as the size of the problem, thus getting a sense of the limit of applicability for the new approach. Furthermore, the algorithm performance is then demonstrated, using the Aimsun simulator, and a large network in Vitoria, Spain.

Simultaneous Perturbation Stochastic Approximation (SPSA)

SPSA is an optimization algorithm favourable for large scale stochastic problems. It provides an advantage over other stochastic algorithms due to its property of requiring only two evaluations of the given objective function to calculate the minimizing gradient. Its working mechanism contains four major steps within an iteration, (1) perturbation of the decision variable with randomness; (2) objective function evaluation for the goodness of fit between the observed and the simulated traffic data; (3) gradient approximation by the ratio of the difference between two evaluations from the objective function and the perturbation magnitude; (4) minimization of the decision variables upon the gradient.

PC–SPSA: Putting together PCA and SPSA for online OD calibration

SPSA is a random search algorithm and its performance deteriorates significantly, when problem dimensions and complexity increase. PCA is combined with SPSA, as a dimension reduction technique, to overcome its limitations, enabling its application on the online calibration of large–scale DTA models. Principal Component Analysis (PCA) [4] maps the variance of a large multivariate dataset into lower dimensional uncorrelated vectors (i.e. principal components). The first principle component (PC) represents the most variance and the scale of representation reduces in a descending order till the first few PCs representing the most variance. With the application of PCA, the number of OD variables to be estimated are reduced to a vector of few PC scores. These PC scores are then calibrated using SPSA.

Case Study: SPSA vs. PC–SPSA

First a synthetic non–linear function is used to explore and compare the efficiency of SPSA and PC–SPSA in a controlled environment. Root Mean Squared Normalized (RMSN) error is used to measure the goodness of fit between the observed and simulated counts. The comparison is performed on eight different dimension problems (see Figure 1). The dimension d represents the number of zones (OD flows will be d^2), while the number of counts are set to be one fifth of the OD flows. Two major conclusions that can be drawn from Figure 1 are: (1) PC–SPSA is able to reach a superior optimal solution significantly faster than SPSA, (2) PC–SPSA also shows robustness against the increase in the number of dimensions, whereas SPSA's performance deteriorates significantly as the scale of the problem increase.

The second case study is on a real life network in Vitoria, Spain. The network consisting of 5,799 links (about 600km in length) and 2884 nodes, is divided into 57 zones making its OD matrix to be of 3249 in dimensions. There are 397 loop detectors. Figure 2 demonstrates the results from the application of both approaches.

Conclusion

In summary, the incorporation of principle component technique with SPSA shows great potential in improving the performance of online OD demand calibration for dynamic traffic assignment (DTA) systems. PC–SPSA shows two advantages over traditional SPSA. First, it can store the variance from historical OD demand over time in the form of PC scores, which provide SPSA with a clear searching direction, instead of a random search. The second advantage is that it reduces the dimensions of a large–scale OD matrix considerably, thus reducing the number of variables to be calibrated. Both advantages make the calibration faster, and the number of iterations to reach a sharp decline in the error metric decreases significantly. PC–SPSA thus shows promising performance that needs to be further explored in the context of online OD demand calibration, but of course also for other application domains.

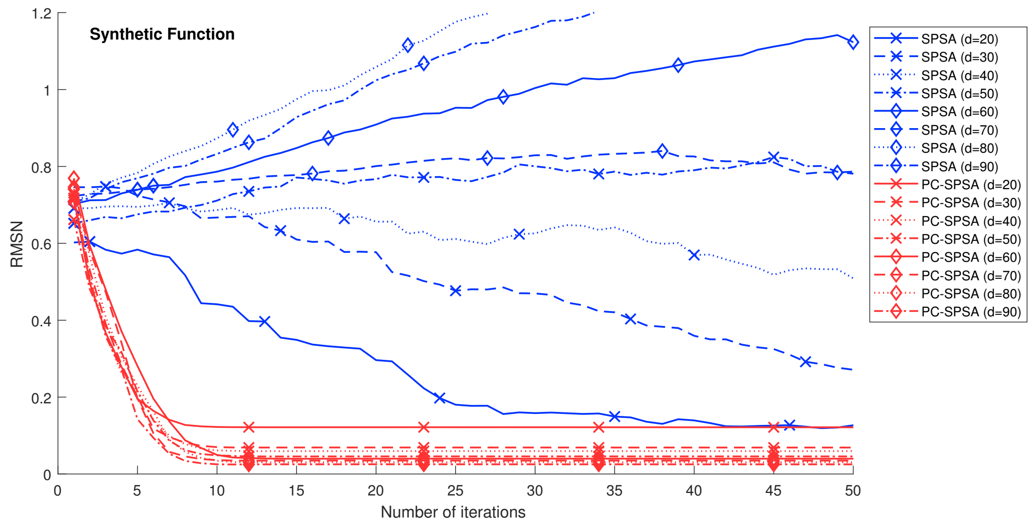

Figure 1: Performance of SPSA and PC–SPSA (different problem dimensions): Synthetic function

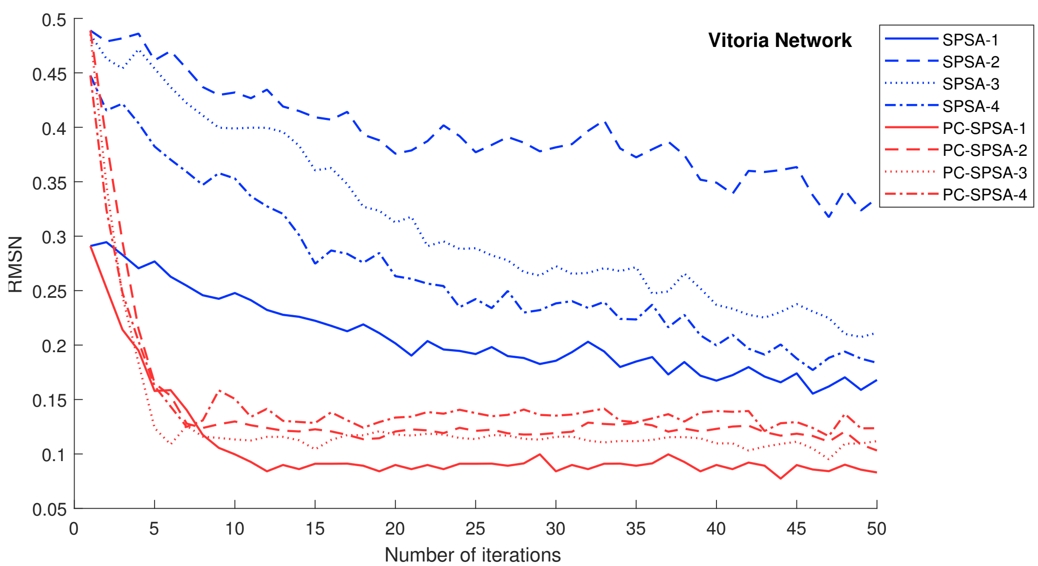

Figure 2: Performance of SPSA and PC–SPSA: Vitoria network

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