Spatio-temporal Traffic Flow Estimation and Optimum Control in Sensor-Equipped Road Networks

Shangbo Wang

Electrical and Data Engineering

University of Technology Sydney

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I would like to dedicate to my parents, Guanfeng Wang and Ping Yang, for their endless love and support.

Declaration

Shangbo Wang declares that this thesis, is submitted in fulfillment of the requirements for the award of PhD degree, in the Electrical and Data Engineering/Faculty of Engineering and Information Technology at the University of Technology Sydney. This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

Shangbo Wang
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"*Es ist absolut möglich, dass jenseits der Wahrnehmung unserer Sinne ungeahnte Welten verborgen sind*" - Albert Einstein

Under the guidance of philosophical truth, this thesis is accomplished during my PhD study in Electrical and Data Engineering, Faculty of Engineering and Information Technology at University of Technology Sydney.

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Abstract

With rapid urbanization, ITS (Intelligent Transportation Systems) has been deployed in some metropolitan areas to relieve traffic congestion and traffic accidents by traffic flow prediction and optimum traffic control. Due to temporary deployment of sensors, sensor malfunction and lossy communication systems, data missing problems has drawn significant attention from both academia and industry. Missing traffic data problem has negative impact on traffic flow prediction and optimum traffic control because ATIS (Advance Traveler Information Systems) and ATMS (Advance Traffic Management Systems) both rely on reliable, accurate and consistent traffic data measurements. Furthermore, adaptive traffic control is the most effective method to relieve traffic congestion and maximize road capacity. In this thesis, an Optimum Closed Cut (OCC) based spatio-temporal imputation technique was proposed, which can fully exploit the spatial-temporal correlation and road topological information in urban traffic network. The road topological information and flow conservation law can be explored to further improve the estimation performance while reducing the number of sensors involved in the data imputation, hence improving the computational efficiency. Besides, this thesis investigated the fundamental limits of missing traffic data estimation accuracy in urban networks using the spatio-temporal random effects (STRE) model. Furthermore, a hybrid dynamical system was investigated, which incorporates flow swap process, green-time proportion swap process and flow divergence for a general network with multiple OD pairs and multiple routes. A novel control policy was proposed to fill the gap by only adjusting the green-time proportion vector, and a sufficient condition was derived for the existence of equilibrium of the dynamical system under the mild constraints that (1) the travel cost function and stage pressure function should be continuous functions; (2) the flow and green-time proportion swap processes project all flow and green-time proportion vectors on the boundary of the feasible region onto itself. The condition of unique equilibrium was derived for fixed green-time proportion vector and it is shown that with varying green-time proportion vector, the set of equilibria is a compact, non-convex set, and with the same partial derivative of travel cost function with respect to the flow and green-time proportion vectors. Finally, the stability of the proposed dynamical system was proved by using Lyapunov stability analysis.

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