UNIVERSITY OF TECHNOLOGY SYDNEY
Faculty of Engineering and Information Technology

Smart Road Sensing for Intelligent Transportation Systems

by

Yimeng Feng

A Thesis Submitted
in Partial Fulfillment of the
Requirements for the Degree

Doctor of Philosophy

Sydney, Australia

2021

Certificate of Authorship/Originality

I, Yimeng Feng declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy (Engineering), in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree at any other academic institution except as fully acknowledged within the text. This thesis is the result of a Collaborative Doctoral Research Degree program with Beijing University of Posts and Telecommunications.

This research is supported by the Australian Government Research Training Program.

Signature of Student: Production Note: Signature removed prior to publication.

Date: 29 Sep 2021

Acknowledgements

The completion of this dissertation has been possible with the inspiration and encouragement from many people, to whom I am greatly indebted.

Firstly, I would like to take this opportunity to express my sincere gratitude to my principal supervisor Professor J. Andrew Zhang and my previous supervisor Professor Guoqiang Mao for their persistent guidance, valuable recommendations, generous advice, never-ending patience and ongoing support. I feel extremely fortunate to be mentored by them during my Ph.D. candidature at UTS. Without their guidance and persistent help, this work would not have been possible. I learnt a lot from their hard-working ethic and self-discipline. The experience of my involvement in a start-up is also valuable and remarkable: I have developed and improved skills besides research, such as problem-solving skill, critical thinking skill, leadership skill, project management skill, resilience ability in the agile working process. I want to thank my co-supervisor Prof. Sean He for his kind guidance, Prof. Justin Lipman and Prof. David McGloin for their wonderful support and generous help during my PhD.

I would like to thank my supervisor Prof. Junliang Chen and Prof. Bo Cheng from Beijing University of Posts and Telecommunications (BUPT) for their guidance and support. Their gentle and thoughful personalities influenced me and I always feel that I have been lucky to have them mentoring me at the early stage of my research. Their kindness was like a beacon for guiding the way in the dark and showing me the road ahead. I would like to inspire and influence others as they did for me.

I am also grateful to have met other members of all of my supervisors' research teams, for their providing a friendly working environment and for their support. I am also grateful to have met so many kind people during my life at UTS, including UTS

SEDE colleagues, UTS Housing members, UTS GRS, UTS Sports, UTS Library, UTS Women in Engineering and IT, my yoga teacher Arpita and my friends from my volunteer experiences, seminars, conferences, Cisco MentorMe program and the place in UTS Building 11 Level 8.

As a dual PhD program student, I am greatly thankful to my colleagues for their great assistance including: Meng Niu, Zhaoning Wang, Zhongyi Zhai, Bingfei Ren for working collaborately at BUPT, Baoqi Huang, Shangbo Wang for the research collaborations at UTS, Zhiwei Yang, Yilong Hui, Zhen Liu, Zhiqiang Chen from Xidian University for the road experiment assistance, Sayed Royel, Wenwei Mo and Yan Huang for providing thesis latex template.

I would like to acknowledge the financial support for this program, provided by the Faculty of Engineering and Information Technology Scholarship, Collaborative Research Degree Program Scholarship from UTS.

I sincerely thank the deepest love and ongoing support from my beloved families during my studies. I am grateful to my mother Yahong Sun, my grandmother Jinlan Zhang for raising me up and backing me up, to my uncles, aunts and my fiance's parents for their encouragement and blessing. Their moral characters are always the models for showing me how to be a good human being.

Finally, but mostly, I wish to express my deepest gratitude to my beloved mother Yahong Sun, my darling fiance Ziqiang Fu and our cutiest ragdoll baby Kokoro, who are always standing by me during this work and giving me faith. From the precious love and endless happiness they have brought to me, I learnt a lot and I understood the world better. Thanks for all the meaningful and beautiful memories we have had together. I consider myself extremely fortunate to have them in the journey of my life. These memories are shining and I will cherish them forever.

Yimeng Feng

Sydney, Australia, 2021

List of Publications

The following is a list of publications in refereed journals and conference proceedings produced during my Ph.D. candidature. In some cases, the journal papers contain material overlapping with the conference publications.

Journals

1. **Y. Feng**, G. Mao, B. Cheng, C. Li, Y. Hui, Z. Xu and J. Chen, "MagMonitor: Vehicle Speed Estimation and Vehicle Classification Through A Magnetic Sensor," in *IEEE Transactions on Intelligent Transportation Systems*, doi: 10.1109/TITS.2020.3024652.

2. **Y. Feng**, J. A. Zhang, B. Cheng, X. He and J. Chen, "Magnetic Sensor Data Association for Multi-Vehicle Tracking," in *IEEE Sensors Journal*, doi: 10.1109/JSEN.2021.3112161

3. M. Niu, B. Cheng, **Y. Feng** and J. Chen, "GMTA: A Geo-Aware Multi-Agent Task Allocation Approach for Scientific Workflows in Container-Based Cloud," in *IEEE Transactions on Network and Service Management*, vol. 17, no. 3, pp. 1568-1581, Sept. 2020, doi: 10.1109/TNSM.2020.2996304.

Conference Proceedings

1. **Y. Feng**, G. Mao, B. Cheng, B. Huang, S. Wang, and J. Chen, "MagSpeed: A Novel Method of Vehicle Speed Estimation Through A Single Magnetic Sensor," *In 2019 IEEE Intelligent Transportation Systems Conference (ITSC)*, pp. 4281-4286. IEEE, 2019.

2. **Y. Feng**, B. Cheng, S. Zhao, Z. Zhai, Z. Wang, M. Niu, and J. Chen. "MobiTemplate: A Template-based Rapid Cross-Platform Mobile Application

Development Environment," In *Proceedings of the 15th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys '17).*

3. L. Wan, G. Chen, and **Y. Feng**, "Multi-Vehicle Tracking and State Estimation through Data Association," *SAE Technical Paper* 2020-01-5149, 2020.

Patent

1. G. Mao and **Y. Feng**,"A vehicle speed estimation method, application, computer hardware and storage middleware," China, CN110310490B, Nov, 2020, https://patents.google.com/patent/CN110310490B/en

Contents

List of Figures

List of Tables

Abstract

In recent years, the field of intelligent transportation has attracted more and more attention. The sensing of Intelligent transportation is currently the focus in intelligent transportation research, and the acquisition of road traffic flow and vehicle speed is an important way of information perception in intelligent transportation system. However, the current road traffic monitoring methods lack a cost-effective method to meet the demand. This research is committed to detecting traffic flow and speed information by deploying low-cost, lightweight magnetic sensors on the road, and providing advanced intelligent road sensing technology for intelligent transportation systems. Specifically, the main research content of this article is embodied in the following aspects:

Research on using a single magnetic sensor for small vehicle detection and speed estimation. This research innovatively proposes a method that use a magnetic sensor to achieve the detection and vehicle speed estimation as multiple sensors, and proposes the use of a magnetic dipole analogous vehicle to establish a vehicle motion model. Besides that, the influence of different directions of the vehicle on the sensor signal detection effect is also carried out, and the direction of the image fluctuation of the sensor's three axes is analyzed, so as to distinguish the different directions of the vehicle.

Research on the detection and classification of multiple vehicle types based on a

single magnetic sensor. This research deeply analyzes the application of electromagnetics to intelligent transportation systems, and derives and verifies the combined model of multiple magnetic dipoles. This research proposes a vehicle type classification technology based on magnetic field fluctuation images. This research deals with small cars, medium-sized cars and large-sized cars, processes and analyzes the degree of response of different types of cars to magnetic field information, and proposes the derivation of a combined speed model.

Research on multi-vehicle data association based on magnetic field sensors. This research proposes a low-cost multi-vehicle and multi-sensor tracking data association framework based on magnetic sensors. Due to the deployment of multiple sensors, the problem of sensor data loss and clock calibration needs to be solved. This research based on Kalman filter to gain vehicle position and speed estimation, as well as the linear discriminant classification model, proposes an efficient and convenient trajectory-oriented multi-hypothesis model.