UNIVERSITY OF TECHNOLOGY, SYDNEY
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DEVELOPMENT OF HYBRID ALGORITHMS FOR VEHICULAR EMISSIONS MODELLING AND PREDICTION

by

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Certificate of Authorship/Originality

I certify that the work in this thesis has not been previously submitted for a degree nor has it been submitted as a part of the requirements for other degree except as fully acknowledged within the text.

I also certify that this thesis has been written by me. Any help that I have received in my research and in the preparation of the thesis itself has been fully acknowledged. In addition, I certify that all information sources and literature used are quoted in the thesis.

Seth Daniel Oduro

ABSTRACT

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The overwhelming accumulation of traffic volumes and relentless changes in travel-related characteristics significantly increase vehicular emissions, and hence, seriously affect urban air quality. It is difficult, however, to accurately estimate vehicular emissions in traffic intersections, junctions, and at signalized roadways because rate models for predicting vehicular emissions are insensitive to the vehicle modes of operations, such as cruising, idling, acceleration and deceleration. The reason is that these models are usually based on the average trip speed, not vehicle dynamics. These contribute to the increased complexity of such a model and degradation of its predictive performance.

This thesis advocates the feasibility of using variables such as vehicle speed, acceleration, load, power and ambient temperature to predict transport emissions to ensure that emission inventories are accurate for the sake of air quality modelling and management planning. A variety of algorithms has been developed, based on Multivariate Adaptive Regression Splines (MARS), Boosting Multivariate Adaptive Regression Splines (BMARS), Artificial Neural Networks (ANNs), as well as the non-parametric Classification and Regression Trees (CART) and a combination of them in hybrid models to improve the accuracy of the emission prediction using vehicles' on-board measurements and chassis dynamometer testing. Several performance indices are used to evaluate: accuracy, flexibility and computational efficiency.

The obtained results suggest that the CART-BMARS hybrid methodology appears to be a useful and fairly accurate tool for predicting microscale vehicle emis-

sions and may be adopted by regulatory agencies. The significance of this thesis is in providing of feasible and effective solutions for the implementation of vehicular emissions models to address the problem of air quality modelling and control in metropoles and mega-cities.

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List of Publications

1. **S.D. Oduro**, Q.P. Ha and H. Duc, (2016) "Vehicular Emissions Prediction with CART-BMARS Hybrid Models", invited for journal submission in *Transportation Research Part D: Transport and Environment.*

2. **S.D. Oduro**, S. Metia, H. Duc, G. Hong, and Q.P. Ha, (2015) "Multivariate Adaptive Regression Splines Models for Vehicular Emission Prediction", *Visualization in Engineering*, vol. 3, no. 1, pp. 13.

3. S. Metia, **S.D. Oduro**, H. Duc, and Q.P. Ha, (2016) "Inverse Air-Pollutant Emission and Prediction Using Extended Fractional Kalman Filtering", *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 9, no. 5, pp. 2051-2063.

4. **S.D. Oduro**, S. Metia, H. Duc and Q.P. Ha, (2015) *Predicting Carbon Monoxide Emissions with Multivariate Adaptive Regression Splines (MARS) and Artificial Neural Networks (ANNs)*, The 32nd International Symposium on Automation and Robotics in Construction and Mining, Oulu, Finland, pp. 912-920.

5. **S.D. Oduro**, S. Metia, H. Duc, G. Hong and Q.P. Ha (2014), *Prediction of NO_X Vehicular Emissions using On-Board Measurement and Chassis Dynamometer Testing*, The 31st International Symposium on Automation and Robotics in Construction and Mining, Sydney, Australia, pp. 584-591.

6. S. Metia, **S.D. Oduro**, H. Duc, and Q.P. Ha (2014), *Air Pollution Prediction Using Matern Function Based Extended Fractional Kalman Filtering*, The 13th International Conference on Control, Automation, Robotics & Vision Marina Bay Sands, Singapore, pp. 758-763.

7. **S.D. Oduro**, S. Metia, H. Duc and Q.P. Ha (2013), *CO_2 vehicular emission statistical analysis with instantaneous speed and acceleration as predictor variables*, The 2nd International Conference on Control, Automation and Information Sciences, Nha Trang, Vietnam, pp. 158-163.

8. S. Metia, **S.D. Oduro**, H. Duc, M. Azzi and Q.P. Ha (2013), *Environmental Time Series Analysis and Estimation with Extended Kalman Filtering*, First International Conference on Artificial Intelligence, Modelling & Simulation, Kita Kinabalu, Malaysisa, pp. 235-240.

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Nomenclature and Notation

Throughout the thesis, the following nomenclatures and notations are used:

- ADR: Australian drive cycle
- AFR: Air-fuel Ratio
- NH_3: Ammonia
- ANNs: Artificial Neural Networks
- ANOVA: Analysis of variance
- BDC: Bottom dead centre
- BFs: Basis functions
- CART: Classification and regression trees
- CH_4: Methane
- CO_2: Carbon dioxides
- CO: Carbon monoxide
- CI: Compression ignition
- CMEM: Comprehensive Modal Emissions Model
- CCF: Congestion Correction Factor
- COPERT: Computer program to calculate emissions from transport
- EGR: Exhaust Gas Re-circulation
- EMIT: EMIssions from Traffic
- F_P: Propulsive force
- GPS: Global positioning system
- GCV: Generalized cross-validation
- HBEFA: Handbook of Emission Factors
- HC: Hydrocarbons
- H_2O: Water
- MARS: Multivariate Adaptive Regression Splines

- MOBILE: Mobile source emission factor
- MOVES: Motor Vehicle Emissions Simulator
- NO: Nitric oxide
- NO_2: Nitrogen dioxides
- NO_X: Nitrogen oxides
- OBD: On-board diagnostics
- O_2: Oxygen
- O_3: Ozone
- PCV: Positive Crankcase Ventilation
- PHEM: Passenger car and Heavy-duty Emissions Model
- PM: Particulate matter
- R_A: Air resistance
- R_G: Gradient resistance
- RPM: Revolutions per minute
- R_R: Rolling resistance
- RSDs: Remote sensing devices
- SI: Spark-ignition
- SO_2: Sulphur dioxide
- THC: Total volatile hydrocarbons
- TDC: Top dead centre
- VKT: Vehicle kilometres travelled
- VOCs: Volatile organic compounds