



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
MECHATRONICS ENGINEERING

Modeling, Simulation, and Development of Stability Control Strategy for Integrated Wheel Vehicles

A Thesis submitted in partial fulfillment of the requirements of the degree of
***Master of Science in Mechanical Engineering
(Mechatronics Engineering)***

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Statement

This thesis is submitted as a partial fulfillment of the degree of Master of Science in Mechanical engineering, Faculty of Engineering, Ain Shams University. The author carried out the work included in this thesis and no part of it has been submitted for a degree or qualification at any other scientific entity.

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Signature

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List of Publications

The following publications have been published while in conduct of this study:

- M. Rawash, M. Abdelaziz, M. Ghoneima and F. Tolbah, “Modular Estimation Strategy of Vehicle Dynamic Parameters for Motion Control Applications, “MATEC Web of Conferences 166, 02006, 2018.

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Abstract

Due to the high number of injuries and fatalities from road crashes, the presence of active safety systems such as Traction Control (TC), Anti-lock Braking System (ABS), and Stability Control (SC) has become a necessity, where statistics have proved their effectiveness in reducing road crashes. SC actively controls the yaw rate and/or side slip angle which define the directional behavior of the vehicle.

In the literature, SC has been researched for decades and with the rising concern regarding the environmental impact of fossil fuel powered vehicles, SC has also migrated into electric vehicles with In-Wheel motors or vehicles with independently driven wheels, referred to in this thesis as Integrated-Wheel (IW) vehicles. This type of vehicles presents a platform for advanced vehicle motion control, but are considered over actuated. Therefore, in this thesis, Model Predictive Control (MPC) is applied for SC of IW vehicles, since it relies on a model for predicting future system states and outputs, and effectively applies the most suitable combination of control actions or inputs according to an objective function. The methods of actuation are individual wheel's driving and braking torque.

Linear Time Varying MPC (LTVMP) was the type of MPC selected for application, due to the nonlinear nature of vehicle dynamics. It is considered the most practical in terms of complexity, accuracy, and computational cost with respect to other types of MPC applicable for nonlinear systems, namely Nonlinear MPC and Hybrid MPC. In LTVMP, the system is linearized about the current operating point at each sample time.

Since tire slip ratio not only affects the longitudinal force developed in the tire contact patch, but also affects the tire's capacity to develop lateral force needed for lateral stability, it was customary for there to exist a separate slip control system, such as TC or ABS, along with SC. However, this compromises the optimality of the control actions demanded by any of both, since it would be later altered by the other. In this work, slip control was integrated into the control system by incorporating wheel dynamics into the prediction model, and the controller works towards stabilizing the vehicle directional behavior and wheel slip together through the same objective function.

Another advantage of using MPC is that limits of capacity of all actuator could be considered when calculating the control actions. The limits of actuator

capacity are regarded as bounds on control actions when solving the objective function using a quadratic programming solver. The proposed controller also offers the advantage that it could be applied to vehicles with different drive configurations, such as front-wheel-drive, rear-wheel-drive, or 4-wheel drive, and vehicles with different parameters with minimal tuning.

A modular estimation strategy was developed to support the controller with vehicle dynamic parameters not measurable by real sensors, due to technical or economic difficulties. The strategy is modular in that each module is concerned with estimating a single type of vehicle parameter, which offers the advantage of being able to upgrade individual modules or add new ones for estimating additional parameters. The parameters estimated by the strategy include: longitudinal, lateral, and vertical tire forces, longitudinal and lateral velocities, vehicle mass, body roll and pitch angles, and total roll and pitch angles. The strategy was also validated by simulations using a 14 Degree Of Freedom (DOF) vehicle model in Matlab and Simulink.

The performance of the proposed stability controller was also validated in a complete simulation environment in Matlab and Simulink comprising a driver model, a 14-DOF vehicle model, the estimation strategy, and the proposed controller. Three maneuvers were carried on, and in all three maneuvers the controller exhibited good performance in tracking the desired yaw rate, maintaining a small side slip angle, and stabilizing wheel slip ratios.

Key words: *stability control, vehicle handling, traction control, in-wheel electric vehicles, model predictive control, linear time varying systems, parameter estimation, modeling and simulation.*

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Table of Contents

Statement.....	i
List of Publications	iii
Researcher Data	v
Abstract	vii
Acknowledgments	ix
Table of Contents	xi
List of Figures	xiii
List of Tables.....	xvii
List of Abbreviations.....	xix
Chapter 1: Introduction	1
1.1. Road Crashes.....	1
1.2. Active safety systems	2
1.3. Stability control	3
1.4. Motivation	5
1.5. Thesis outline	6
Chapter 2: Literature review	7
2.1. Literature review on stability control	7
2.1.1. Stability analysis	7
2.1.2. Envelope control	9
2.1.3. Reference tracking control	10
2.1.4. Stability control using model predictive control	11
2.1.5. Nonlinear model predictive control.....	12
2.1.6. Hybrid model predictive control	12
2.1.7. Linear time varying model predictive control.....	13
2.1.8. Integration of stability control and wheel slip control.....	14
2.2. Literature review on vehicle parameters estimation.....	15
2.3. Summary	18
Chapter 3: Vehicle Modeling	19
3.1. 14-DOF vehicle model	19
3.2. Tire model	21
3.3. Sensors model	22
Chapter 4: Estimation strategy	25
4.1. Longitudinal tire force estimation	26