

Table of Contents

List of Figures	ix
List of Tables	xi
List of Abbreviations	xiii
List of Symbols	xv
Abstract	xxiii
Deutsche Kurzfassung	xxv
1 Introduction	1
1.1 Motivation	1
1.2 Overview of the Research Area	3
1.2.1 Model Reduction	4
1.2.2 Bounds for the Error of Model Reduction	6
1.2.3 MPC Using Reduced Models	8
1.2.4 Summary	10
1.3 Contributions of the Thesis	12
1.4 Design Workflow of the Proposed Model Predictive Control Scheme	14
1.5 Outline of the Thesis	14
2 Background	17
2.1 Model Reduction	17
2.1.1 Model Reduction by Projection	18
2.1.2 Model Reduction by Proper Orthogonal Decomposition	20
2.2 A-Posteriori Bounds for the Model Reduction Error	21
2.3 Model Predictive Control	23
2.3.1 Problem Setup	23
2.3.2 Principle of Model Predictive Control	25
2.3.3 Guarantees in Model Predictive Control	27
2.3.4 Model Predictive Control Using Reduced Models	28
2.4 Nonisothermal Tubular Chemical Reactor	30
2.4.1 Derivation of the Plant Model	31
2.4.2 Problem Setup for Model Predictive Control	33

3	Trajectory-Based Model Reduction for Nonlinear Systems	37
3.1	Problem Statement	37
3.2	Procedure of Trajectory-Based Model Reduction	39
3.2.1	Evaluation of the Objective Functional	40
3.2.2	Parameterization of the Reduced Model	40
3.2.3	Estimation of the Reduced Model	41
3.2.4	Complexity Reduction of the Reduced Model	43
3.2.5	Example: MAPK Cascade	44
3.3	Preserving Stability in Trajectory-Based Model Reduction	49
3.3.1	Location and Stability of Steady States	49
3.3.2	Model Reduction Ensuring Steady State Properties	51
3.3.3	Formulation as Sequential Convex Optimization	52
3.3.4	Model Reduction Algorithm	53
3.3.5	Example: Fermi-Pasta-Ulam Lattice	54
3.4	Comparison with Approaches Relying Only on Simulated Trajectories	57
3.5	Summary	58
4	A-Posteriori Bound for the Model Reduction Error	59
4.1	Problem Statement	60
4.2	Preprocessing of the Plant	61
4.3	A Bound for the Norm of the Matrix Exponential	62
4.4	Asymptotically Stable Error Bounding System	64
4.4.1	Improved A-Posteriori Error Bound	64
4.4.2	Achieving an Asymptotically Stable Error Bounding System	66
4.4.3	Relation to Existing A-Posteriori Error Bounds	67
4.5	Example: Tubular Reactor	68
4.5.1	Preprocessing and Bounding the Norm of the Matrix Exponential	68
4.5.2	Model Reduction	69
4.5.3	A-Posteriori Bound for the Model Reduction Error	70
4.5.4	Computational Demand	73
4.6	Summary	74
5	MPC Using Reduced Models for Continuous-Time Systems	75
5.1	Problem Statement	76
5.2	Preprocessing and Model Reduction	77
5.3	Guaranteeing Constraint Satisfaction	81
5.4	MPC Scheme Using the Reduced Model and Error Bound	82
5.5	Eliminating the Model Reduction Error in the Cost Functional	86
5.6	Guaranteeing Asymptotic Stability	92
5.7	Relation to Existing Approaches	100
5.8	Example: Tubular Reactor	101
5.8.1	Design of the Model Predictive Controllers	102

5.8.2	Time Response	103
5.8.3	Computational Complexity	103
5.8.4	Performance	106
5.9	Summary	107
6	MPC Using Reduced Models for Discrete-Time Systems	109
6.1	Problem Statement	110
6.2	MPC Scheme Using the Reduced Model and Error Bound	111
6.3	Equivalence of the Optimization Problem to a Second-Order Cone Problem	114
6.4	Example: Tubular Reactor	119
6.5	Summary	121
7	Conclusions	123
7.1	Summary	123
7.2	Outlook	125
A	Linearization and Spatial Discretization of the Tubular Reactor	129
B	Model of the MAPK Cascade	133
C	Application of the MPC Schemes to a Two-Dimensional System	137
C.1	Problem Setup	137
C.2	Design of the Model Predictive Controllers	137
C.3	Time Response	139
C.4	Asymptotic Stability	139
C.5	Performance	139
C.6	Region of Attraction	141
	Bibliography	143