

# Table of Contents

<b>List of Figures</b>	<b>ix</b>
<b>List of Tables</b>	<b>xi</b>
<b>List of Abbreviations</b>	<b>xiii</b>
<b>List of Symbols</b>	<b>xv</b>
<b>Abstract</b>	<b>xxiii</b>
<b>Deutsche Kurzfassung</b>	<b>xxv</b>
<b>1 Introduction</b>	<b>1</b>
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
<b>2 Background</b>	<b>17</b>
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

<b>3 Trajectory-Based Model Reduction for Nonlinear Systems</b>	<b>37</b>
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
<b>4 A-Posteriori Bound for the Model Reduction Error</b>	<b>59</b>
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
<b>5 MPC Using Reduced Models for Continuous-Time Systems</b>	<b>75</b>
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
<b>6</b>	<b>MPC Using Reduced Models for Discrete-Time Systems</b>	<b>109</b>
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
<b>7</b>	<b>Conclusions</b>	<b>123</b>
7.1	Summary . . . . .	123
7.2	Outlook . . . . .	125
<b>A</b>	<b>Linearization and Spatial Discretization of the Tubular Reactor</b>	<b>129</b>
<b>B</b>	<b>Model of the MAPK Cascade</b>	<b>133</b>
<b>C</b>	<b>Application of the MPC Schemes to a Two-Dimensional System</b>	<b>137</b>
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
<b>Bibliography</b>		<b>143</b>