

Contents

1. Introduction	1
2. Theoretical Background and Literature Review	5
2.1. Semi-Infinite Programs	5
2.1.1. Discretization Methods	6
2.1.2. Local Reduction Methods	6
2.2. Dynamic Optimization	7
2.2.1. State-of-the-Art: Dynamic Optimization under Uncertainty	9
2.2.2. Challenges of Finding the Worst Cases	10
2.3. Economic Model Predictive Control	10
2.3.1. Robust Control	12
3. Case Studies	17
3.1. Modified Penicillin Fermentation	17
3.1.1. Problem Description	18
3.1.2. Optimization Results - Nominal Case	20
3.2. Emulsion Polymerization	22
3.2.1. Problem Description	22
3.2.2. Optimization Results - Nominal Case	24
4. Robust Dynamic Optimization Utilizing SIP Approaches	27
4.1. Applying SIP Algorithms to Dynamic Optimization Problems	27
4.1.1. Discretization Approach	31
4.1.2. Local Reduction Approach: KKT-Embedding	35
4.1.3. Theoretical Comparison	41
4.2. Case Study: Modified Penicillin Fermentation	42
4.2.1. Discretization	43
4.2.2. KKT-Embedding	46
4.2.3. Evaluation and Discussion	48
4.3. Summary	51
5. Heuristic Approximations for Robust Dynamic Optimization	53
5.1. Two-Model Approach	53
5.1.1. Sensitivity Analysis	54
5.1.2. Selection of the Worst-Case Parameter Values	56

5.1.3.	Optimization Results	57
5.1.4.	Comparison of Control Trajectories	58
5.1.5.	Discussion	58
5.2.	Multi-Model Approach	60
5.2.1.	Generating Worst-Case Models Based on Sensitivity	61
5.2.2.	Case Study I: Semi-Batch Emulsion Polymerization	65
5.2.3.	Case Study II: Penicillin Fed-Batch Fermentation	72
5.3.	Summary	79
6.	Robust Feasible Control	81
6.1.	Robust Control with Multi-Scenario eNMPC	81
6.1.1.	Robust eNMPC with Scenarios from Discretization Approach	82
6.1.2.	Heuristic Robust eNMPC Based on Sensitivities	82
6.2.	Case Study: Modified Penicillin Fermentation	82
6.2.1.	Problem Description	83
6.2.2.	Results with Nominal Process Model	83
6.2.3.	Results with Uncertainty in the Process Model	86
6.2.4.	Discussion	89
6.3.	Summary	92
7.	Summary and Outlook	95
7.1.	Summary and Conclusion of this Work	95
7.2.	Outlook to Future Research	98
Bibliography		103
A. Linear One-Dimensional Dynamic Example		113
B. Time-Varying Worst-Case Parameter Value		115
C. Application of Heuristic Approach to Modified Penicillin Fermentation		121