
Contents

1	Introduction to Control Reconfiguration	1
1.1	Fault-Tolerant Control	1
1.2	Fault Detection	2
1.3	Control Reconfiguration	3
1.4	Reconfiguration Goal	5
1.5	Aim of this Manuscript	5
1.6	Structure of the Manuscript	6
2	Literature Overview	9
2.1	Fault-Tolerant Control	9
2.2	Specific Reconfiguration Approaches	10
2.3	General Reconfiguration Approaches	11
2.4	Alternatives to Reconfiguration	12
2.5	Advanced Control Theory	14

Part I. Reconfiguration Problem

3	Running Example: the 2-Tank System	17
3.1	Nonlinear Model	17
3.2	Linear Model	18
3.3	Controller	19
3.4	Faults	20
3.5	Analysis	21

4	General Reconfiguration Problem	25
4.1	Overview	25
4.2	Modelling the System and the Fault	25
4.3	Control Loop	28
4.4	Reconfiguration Block	31
4.5	Reconfiguration Goals	33
4.6	2-Tank Example	38
5	Linear Reconfiguration Problem	41
5.1	Nominal Control Loop	41
5.2	Fault and Reconfiguration	42
5.3	Reconfiguration Goals	45
5.4	Specific Faults	47
5.5	2-Tank Example	50

Part II. Linear Solution Approaches

6	Direct Reconfiguration Using a Static Block	55
6.1	Direct Reconfiguration After Actuator Faults	55
6.2	Solvability Consideration	56
6.3	Derivation of a Static Reconfiguration Block	57
6.4	Reconfiguration Algorithm	59
6.5	Analysis	60
6.6	Application to the 2-Tank Example	62
6.7	Pseudo-Inverse Method	63
6.8	Reconfiguration After Sensor Faults	66
6.9	Conclusion	67

7	Reconfiguration Using a Virtual Sensor	69
7.1	Stabilising Reconfiguration After Sensor Faults	69
7.2	Solvability Consideration	70
7.3	Derivation of the Virtual Sensor	71
7.4	Reconfiguration Algorithm	74
7.5	Analysis of the Virtual Sensor	75
7.6	Application to the 2-Tank Example	78
7.7	Conclusion	79
8	Reconfiguration Using a Virtual Actuator	81
8.1	Stabilising Reconfiguration After Actuator Faults	81
8.2	Solvability Consideration	82
8.3	Derivation of the Virtual Actuator	83
8.4	Reconfiguration Algorithm	88
8.5	Analysis of the Reconfigured Closed-Loop System	89
8.6	Application to the 2-Tank Example	92
8.7	Duality of Virtual Sensor and Actuator	96
8.8	Reconfiguration After Internal Faults	98
8.9	Conclusion	101
9	Reconfiguration with Set-Point Tracking	103
9.1	Weak Reconfiguration After Actuator Faults	103
9.2	Solvability Consideration	104
9.3	Approach 1: Zero Placement	105
9.4	Approach 2: Integrating Controller	110
9.5	Analysis and Comparison	112
9.6	Application to the 2-Tank Example	114
9.7	Dual Approach For Sensor Faults	116
9.8	Conclusion	117

10	Reconfiguration by Disturbance Decoupling	119
10.1	Strong Reconfiguration After Actuator Faults	119
10.2	Solvability Condition	120
10.3	Interpretation as a Disturbance Decoupling Problem	122
10.4	Geometric Approach	125
10.5	Reconfiguration Algorithm	130
10.6	Analysis of Reconfigured System	132
10.7	Application to the 2-Tank Example	135
10.8	Dual Approach for Sensor Faults	138
10.9	Conclusion	139

Part III. Structural Tests for Control Reconfiguration

11	Structural Models	143
11.1	Introduction to Structural Models	143
11.2	Structural Matrices	144
11.3	Structural Digraphs	148
11.4	Paths in a Structural Graph	150
11.5	Digraphs and Matrix Models	152
11.6	Weighted Digraphs	154
11.7	Bi-partite Graphs	156
11.8	Structure of Non-Linear Systems	158
11.9	Diagnosis Based on Structural Graphs	159
12	Basic Structural Properties	161
12.1	Defining Structural Properties	161
12.2	s-Controllability and s-Observability	162
12.3	Stabilisability	165
12.4	Reduced Control Problem	167
12.5	Solvability of the Weak Reconfiguration Problem	169
12.6	Application to the 2-Tank Example	170

13 Solvability of Disturbance Decoupling	173
13.1 Disturbance Decoupling	173
13.2 Variants of the Disturbance Decoupling Problem	174
13.3 Disturbance Decoupling of the First Kind	177
13.4 Structural Rank of a System	178
13.5 Almost Disturbance Decoupling	181
13.6 Known-Disturbance Decoupling	183
13.7 Finding a Minimal Difference System	184
14 Structural Solutions to Disturbance Decoupling	189
14.1 Idea of the Iterative Algorithm	189
14.2 Algorithm for Single-Variable Decoupling	190
14.3 Structural Test	193
14.4 Matrix-Based Algorithm for Single-Variable Decoupling	194
14.5 Optimising the Matrix-Based Algorithm	198
14.6 Multi-variable Cancellation	199
14.7 Strong Structural Test	201
15 A Structural Reconfiguration Algorithm for Actuator Faults	205
15.1 Test for Reconfigurability	205
15.2 Reconfiguration After Actuator Faults	207
15.3 Reconfiguration in a Fault-Tolerant Control Scheme	210
15.4 Conclusion	211

Part IV. Application Examples

16 Reconfiguration of the 3-Tank System	215
16.1 Nominal 3-Tank System	215
16.2 Valve 2 Blocked Open	220
16.3 Valve 2 Blocked Closed	223
16.4 Pump 1 Blocked	224
16.5 Conclusion	227

17	Reconfiguration of a Helicopter Model	229
17.1	Helicopter Model	229
17.2	Fault in a Main Rotor	233
17.3	Fault in Both Main Rotors	236
17.4	Fault in the Lateral Rotors	239
17.5	Conclusion	242
18	Conclusion	243
18.1	Summary	243
18.2	Outlook	244
<hr/>		
Part V. Appendices		
<hr/>		
	Glossary	249
A.1	Terms of Fault-Tolerant Control	249
A.2	List of Important Symbols	251
	RECONF – A Toolbox for Reconfiguration	253
B.1	Overview	253
B.2	MATLAB Functions	253
B.3	Simulink Integration	255
	References	261