

# Contents

Dedication	V
Preface	VII
Table of Contents	XIII
List of Tables	XVII
List of Figures	XIX
Nomenclature	XXI
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 Fault Tolerant Control System (FTCS) . . . . .	1
1.1.1 Definition of FTCS . . . . .	1
1.1.2 Classification of FTCS . . . . .	2
1.2 Background and Motivations . . . . .	4
1.3 Advances in Fault Tolerant Control Systems . . . . .	6
1.4 Scope of the Book . . . . .	9
<b>2 ACTIVE FAULT TOLERANT CONTROL IN PROSPECTIVE</b>	<b>11</b>
2.1 Introduction . . . . .	11
2.2 Faults in Dynamic Systems . . . . .	11
2.3 Fault Detection and Identification (FDI) . . . . .	13
2.3.1 Approaches to FDI . . . . .	13
2.3.2 Diagnostic procedure of FDI . . . . .	16
2.3.3 Performance measures in FDI . . . . .	17
2.4 Control System Reconfiguration . . . . .	18
2.5 Applications of FTCS . . . . .	20
<b>3 STOCHASTIC STABILITY</b>	<b>22</b>
3.1 Introduction . . . . .	22
3.2 Definitions of Stochastic Stability . . . . .	23
3.3 Conditions for Stochastic Stability . . . . .	26

<b>4</b>	<b>FTCS WITH MARKOVIAN PARAMETERS (FTCSMP)</b>	<b>30</b>
4.1	Mathematical Models . . . . .	31
4.1.1	Dynamical system models . . . . .	31
4.1.2	Failure and FDI processes . . . . .	33
4.2	Calculation of Transition Rates . . . . .	35
4.3	The Uniqueness of FTCSMP Model . . . . .	37
4.3.1	Errors in detection and identification . . . . .	37
4.3.2	Detection delays and false alarms . . . . .	37
4.4	Stochastic Stability of FTCSMP . . . . .	38
4.4.1	Supermartingales . . . . .	39
4.4.2	Stochastic Lyapunov functions . . . . .	39
4.4.3	The weak infinitesimal operator . . . . .	40
4.4.4	Dynkin's formula . . . . .	41
4.4.5	Conditions for stochastic stability . . . . .	43
<b>5</b>	<b>STOCHASTIC STABILITY OF FTCSMP</b>	<b>45</b>
5.1	Introduction . . . . .	45
5.2	Stochastic Stability of FTCSMP in the Presence of Noise . . . . .	46
5.2.1	Dynamical model of FTCSMP in the presence of noise . . . . .	47
5.2.2	Sufficient conditions for stochastic stability . . . . .	49
5.2.3	Necessary conditions for stochastic stability . . . . .	53
5.2.4	A necessary and sufficient condition for exponential stability . . . . .	56
5.2.5	A numerical example . . . . .	61
5.3	Stability of FTCSMP with Multiple Failure Processes . . . . .	67
5.3.1	Dynamical model of FTCSMP with multiple failures . . . . .	68
5.3.2	Transition probabilities for failure and FDI processes . . . . .	70
5.3.3	Stochastic stability . . . . .	70
5.3.4	A necessary and sufficient condition for exponential stability . . . . .	72
5.3.5	Remarks and special cases . . . . .	76
5.3.6	A numerical example . . . . .	79
5.4	Chapter Summary . . . . .	82
<b>6</b>	<b>PERFORMANCE AND STABILITY OF FTCSMP UNDER IM- PERFECT FDI</b>	<b>83</b>
6.1	Introduction . . . . .	83
6.2	Effects of Detection Delays on the Stability of FTCSMP . . . . .	84
6.2.1	Dynamical model of FTCSMP with detection delays . . . . .	85

6.2.2	Interpretation of detection delays in FDI process . . . . .	85
6.2.3	Exponentially distributed detection delays . . . . .	86
6.2.4	$\gamma$ distributed detection delays . . . . .	86
6.2.5	A necessary and sufficient condition for stochastic stability . . . . .	88
6.2.6	A numerical example . . . . .	89
6.3	Effects of Detection Errors on the Stability of FTCSMP . . . . .	92
6.3.1	A new FTCSMP model . . . . .	93
6.3.2	The role of FDI in fault tolerant control law design . . . . .	94
6.3.3	A necessary and sufficient condition for stochastic stability . . . . .	97
6.3.4	A numerical example . . . . .	97
6.4	Chapter Summary . . . . .	101

**7 FTCSMP WITH ACTUATOR SATURATION AND PARAMETER UNCERTAINTIES 103**

7.1	Introduction . . . . .	103
7.2	Stability of FTCSMP Driven by Actuators with Saturation . . . . .	104
7.2.1	Dynamical model of FTCSMP with actuator saturation limit . . . . .	105
7.2.2	Actuators with saturation limits . . . . .	105
7.2.3	Exponential stability of FTCSSA . . . . .	106
7.2.4	A sufficient condition for exponential stability of FTCSSA . . . . .	109
7.2.5	Remarks and special cases . . . . .	113
7.2.6	A numerical example . . . . .	119
7.3	Stabilization of FTCSMP with Parameter Uncertainties . . . . .	124
7.3.1	Dynamical model of FTCSMP with parameter uncertainties . . . . .	126
7.3.2	The model of parameter uncertainties . . . . .	128
7.3.3	Stabilization of uncertain FTCSMP . . . . .	129
7.3.4	Special cases . . . . .	138
7.3.5	A numerical example . . . . .	141
7.4	Chapter Summary . . . . .	146

**8 SYNTHESIS OF FAULT TOLERANT CONTROL LAWS 148**

8.1	Introduction . . . . .	148
8.2	Design Approaches to Fault Tolerant Control Laws . . . . .	150
8.2.1	The problem statement . . . . .	150
8.2.2	A control law on finite time horizon . . . . .	153
8.2.3	Control laws on infinite time horizons . . . . .	158
8.2.4	A numerical example . . . . .	163

8.3	A Fault Tolerant Control Law in Noisy Environment . . . . .	169
8.3.1	The problem statement . . . . .	169
8.3.2	A control law on finite time horizon . . . . .	170
8.3.3	A control law on infinite time horizon . . . . .	173
8.3.4	A numerical example . . . . .	180
8.4	Chapter Summary . . . . .	181
<b>9</b>	<b>EPILOGUE</b>	<b>184</b>
9.1	Summary . . . . .	184
	<b>BIBLIOGRAPHY</b>	<b>188</b>
	<b>INDEX</b>	<b>207</b>