
Contents

Preface	xv
Author	xvii
Chapter 1 Introduction	1
1.1 Current UAV Presentation	1
1.2 Autonomous Aircraft	4
1.3 Smart Autonomous Aircraft	9
1.4 Outline of the Book	11
Chapter 2 Modeling	19
2.1 Introduction	19
2.2 Reference Frames and Coordinate Systems	20
2.2.1 Inertial Frame	21
2.2.2 Earth-Centered Reference Frame	21
2.2.2.1 Geocentric-inertial frame	21
2.2.2.2 Earth frame	21
2.2.3 Geographic Frame	21
2.2.3.1 Navigation frame	21
2.2.3.2 Tangent plane frame	22
2.2.4 Body Frame	22
2.2.5 Wind Frame	24
2.2.6 Special Euclidean Group	25
2.3 Kinematic Models	26
2.3.1 Translational Kinematics	27
2.3.2 Six Degrees of Freedom Formulation	27
2.3.3 Special Euclidean Space	28
2.3.4 Curvature and Torsion	28
2.4 Dynamic Models	29
2.4.1 Aerodynamics Forces and Moments	30
2.4.1.1 Negligible side-slip angle	32
2.4.1.2 Nonnegligible side-slip angle	33
2.4.2 Translational Dynamics: Coordinated Flight	34
2.4.2.1 Aircraft at constant altitude	38
2.4.2.2 Aircraft in a vertical flight	39
2.4.3 Translational Dynamics: Noncoordinated Flight	39

2.4.4	Six Degrees of Freedom Dynamics.....	40
2.4.4.1	General formulation.....	40
2.4.4.2	Poincaré formulation.....	42
2.4.4.3	Longitudinal model.....	42
2.4.4.4	Lateral model.....	43
2.4.5	Uncertainty.....	44
2.5	Multi-Model Approach.....	48
2.5.1	Global Representation from Local Models	48
2.5.2	Linear Approximate Model.....	49
2.5.2.1	Linear longitudinal model.....	50
2.5.2.2	Linear lateral model.....	51
2.5.2.3	Linear translational model.....	51
2.5.3	Linear Parameter Varying Model: Takagi-Sugeno Formulation.....	53
2.5.3.1	Longitudinal model.....	56
2.5.3.2	Lateral model.....	57
2.5.3.3	Multi-model approach for tracking error model for an aircraft at constant altitude	59
2.5.3.4	Multi-model approach for tracking error model for a 3D aircraft	61
2.5.4	Fuzzy Modeling	66
2.5.4.1	Type 1 Mamdani approach.....	66
2.5.4.2	Fuzzy estimation of Takagi-Sugeno models.....	68
2.5.4.3	Type 2 fuzzy systems.....	70
2.5.5	Linear Hybrid Automaton	74
2.5.5.1	Stochastic linear hybrid system	75
2.5.5.2	State transition.....	76
2.5.5.3	Specific fuel consumption.....	77
2.6	Mission Tools	77
2.6.1	Sensors.....	78
2.6.2	Camera Model.....	81
2.6.3	Software.....	82
2.6.3.1	Petri nets	84
2.6.3.2	Middleware	84
2.6.4	Human Supervisory Modeling	85
2.6.4.1	Operator modeling.....	86
2.6.4.2	Retrial queuing model	87
2.7	Atmosphere.....	88
2.7.1	Gusts and Wind Shear	90
2.7.2	Turbulence.....	92
2.8	Conclusion.....	95

Chapter 3 Flight Control 103

- 3.1 Introduction 103
- 3.2 Linear Control Methods 105
 - 3.2.1 Properties of Linear Systems 105
 - 3.2.1.1 Controllability and observability..... 105
 - 3.2.1.2 Stability of a linear system 106
 - 3.2.2 Linear Approaches for LTI Models 108
 - 3.2.2.1 PID control 109
 - 3.2.2.2 Classical methods 109
 - 3.2.2.3 Adaptive approach..... 111
 - 3.2.2.4 Robust control method for LTI models..... 114
 - 3.2.3 Gain Scheduling..... 117
 - 3.2.4 Receding Horizon Approach for LTV Models 118
 - 3.2.5 Linear Parameter Varying Models..... 119
 - 3.2.5.1 Principle 120
 - 3.2.5.2 Parallel distributed compensator 122
 - 3.2.5.3 Integral action..... 124
 - 3.2.5.4 Gain scheduling 126
 - 3.2.5.5 Cost control analysis: Actuator saturation..... 129
- 3.3 Nonlinear Control 131
 - 3.3.1 Affine Formulation of Aircraft Models..... 131
 - 3.3.1.1 Affine formulation without drift 135
 - 3.3.1.2 Affine formulation with drift..... 136
 - 3.3.1.3 Properties 139
 - 3.3.1.4 Decoupling by feedback linearization 140
 - 3.3.2 Input/Output Linearization 142
 - 3.3.3 Dynamic Inversion..... 143
 - 3.3.4 Control Lyapunov Function Approach 145
 - 3.3.4.1 Properties 146
 - 3.3.4.2 Trajectory tracking 147
 - 3.3.4.3 Path tracking 149
 - 3.3.4.4 Circular path following in wind with input constraints..... 151
 - 3.3.4.5 Tracking of moving targets with wind term 153
 - 3.3.4.6 Suboptimal control 155
 - 3.3.4.7 Measurement error input to state stability..... 161
 - 3.3.4.8 Control Lyapunov function based adaptive control 163

	3.3.4.9	Noisy system.....	164
	3.3.4.10	Backstepping control for affine systems with drift	166
	3.3.4.11	Sliding mode control.....	172
	3.3.5	Model Predictive Control	181
3.4		Fuzzy Flight Control.....	183
	3.4.1	Fuzzy Approach for Tracking Moving Targets.....	184
	3.4.2	Stabilization of Takagi–Sugeno Systems under the Imperfect Premise Matching	186
	3.4.3	Fuzzy Model Predictive Control for Wind Disturbances Rejection	189
3.5		Conclusion.....	192
Chapter 4		Flight Planning	199
	4.1	Introduction	199
	4.2	Path and Trajectory Planning	202
	4.2.1	Trim Trajectories.....	204
	4.2.2	Trajectory Planning.....	205
	4.2.2.1	Time optimal trajectories	205
	4.2.2.2	Nonholonomic motion planning	206
	4.2.3	Path Planning.....	209
	4.2.3.1	B-spline formulation	210
	4.2.3.2	Cubic Hermite spline	211
	4.2.3.3	Quintic Hermite spline.....	211
	4.2.3.4	Pythagorean hodographs	212
	4.2.4	Zermelo’s Problem.....	213
	4.2.4.1	Initial Zermelo’s problem.....	213
	4.2.4.2	2D Zermelo’s problem on a flat Earth	216
	4.2.4.3	3D Zermelo’s problem on a flat Earth	217
	4.2.4.4	3D Zermelo’s problem on a spherical Earth	219
	4.2.4.5	Virtual goal.....	221
4.3		Guidance and Collision/Obstacle Avoidance	222
	4.3.1	Guidance	223
	4.3.1.1	Proportional navigation.....	224
	4.3.1.2	Method of adjoints.....	225
	4.3.1.3	Fuzzy guidance scheme	226
	4.3.2	Static Obstacles Avoidance	229
	4.3.2.1	Discrete methods	231
	4.3.2.2	Continuous methods	241
	4.3.3	Moving Obstacles Avoidance.....	244

- 4.3.3.1 D^* algorithm 245
- 4.3.3.2 Artificial potential fields 247
- 4.3.3.3 Online motion planner 248
- 4.3.3.4 Zermelo-Voronoi diagram 249
- 4.3.4 Time Optimal Navigation Problem with Moving and Fixed Obstacles 253
 - 4.3.4.1 Problem formulation 253
 - 4.3.4.2 Control parametrization and time scaling transform 254
 - 4.3.4.3 RRT variation 255
- 4.4 Mission Planning 256
 - 4.4.1 Traveling Salesman Problem 258
 - 4.4.2 Replanning or Tactical and Strategic Planning 263
 - 4.4.3 Route Optimization 265
 - 4.4.3.1 Classic approach 265
 - 4.4.3.2 Dynamic multi-resolution route optimization 268
 - 4.4.4 Fuzzy Planning 271
 - 4.4.4.1 Fuzzy decision tree cloning of flight trajectories 272
 - 4.4.4.2 Fuzzy logic for fire fighting aircraft 275
 - 4.4.5 Coverage Problem 277
 - 4.4.5.1 Patrolling problem 277
 - 4.4.5.2 Routing problem 281
 - 4.4.5.3 Discrete stochastic process for aircraft networks 283
 - 4.4.5.4 Sensor tasking in multi-target search and tracking applications 287
 - 4.4.6 Resource Manager for a Team of Autonomous Aircraft 292
 - 4.4.6.1 Routing with refueling depots for a single aircraft 293
 - 4.4.6.2 Routing with refueling depots for multiple aircraft 296
- 4.5 Conclusion 298

Chapter 5 Flight Safety 311

- 5.1 Introduction 311
- 5.2 Situation Awareness 313
 - 5.2.1 Filters 314
 - 5.2.1.1 Classical Kalman filter 314
 - 5.2.1.2 Extended Kalman filter 316

5.2.1.3	Unscented Kalman filter	318
5.2.1.4	Monte Carlo filter	321
5.2.1.5	Particle filter	323
5.2.1.6	Wind estimation	326
5.2.2	Aerial Simultaneous Localization and Mapping	328
5.2.2.1	Problem formulation	328
5.2.2.2	Inertial SLAM algorithm	332
5.2.2.3	Sense-and-avoid setup	336
5.2.2.4	Monocular visual-inertial SLAM using fuzzy logic controllers	338
5.2.3	Geolocation	339
5.2.3.1	Cooperative geolocation with articulating cameras	339
5.2.3.2	Geolocation with bias estimation	341
5.3	Integrated System Health Monitoring	342
5.3.1	Diagnostic Tools and Approaches	346
5.3.1.1	Sensor selection and optimization	349
5.3.1.2	Hazard alerting	350
5.3.1.3	Fault tree analysis	351
5.3.1.4	Failure modes and effects analysis	354
5.3.2	Risk-Based Sensor Management	355
5.3.2.1	Bayesian sequential detection	356
5.3.2.2	Bayesian sequential estimation	357
5.4	Fault Tolerant Flight Control	358
5.4.1	Linear Time Invariant Formulation	359
5.4.2	Linear Parameter Varying Formulation	360
5.4.2.1	Short-period dynamics	360
5.4.2.2	General formulation	361
5.4.3	Sliding Mode Approach	364
5.4.4	Direct Model Reference Adaptive Control	366
5.4.4.1	Linear approach	366
5.4.4.2	Nonlinear approach	370
5.4.5	Backstepping Approach	372
5.4.6	Control Probabilistic Methods	374
5.5	Fault Tolerant Planner	377
5.5.1	Artificial Intelligence Planners	377
5.5.2	Trim State Discovery	378
5.5.3	Obstacle/Collision Avoidance Systems	384
5.5.3.1	Safety analysis of collision/obstacle avoidance system	384
5.5.3.2	Informative motion planning	386
5.5.4	Geometric Reinforcement Learning for Path Planning	387

Contents	xiii
5.5.5 Probabilistic Weather Forecasting.....	389
5.5.6 Risk Measurement	391
5.6 Conclusion.....	393
Chapter 6 General Conclusions.....	403
Acronyms.....	405
Nomenclature.....	411
Index.....	415