
Contents

Introduction	xi
Franck CAZAURANG, Manish KUMAR and Kelly COHEN	
Chapter 1. Integration in the National Airspace (Europe and USA) – UAV Classification and Associated Missions, Regulation and Safety, Certification and Air Traffic Management	1
George Thomas BLACK, Kelly COHEN and Catherine RONFLÉ-NADAUD	
1.1. The challenge of UAS integration in the airspace	1
1.1.1. Definitions (ICAO)	2
1.1.2. UAS missions	3
1.1.3. ATM principles and consequences for UAS	4
1.1.4. UAS integration in the airspace	6
1.2. Main stakeholders (ICAO, JARUS, EASA and national regulators)	7
1.2.1. ICAO	7
1.2.2. Joint Authorities for Rulemaking on Unmanned Systems (JARUS)	9
1.2.3. European Aviation Safety Agency (EASA)	10
1.3. French regulation	12
1.4. Communication issues	16
1.5. Next steps for UTM/U-space	17
1.6. Obtaining a remote pilot certificate.	19
1.7. References	25

Chapter 2. UAV Classification and Associated Mission Planning	27
Jean-Louis ROCH	
2.1. UAS classification, general remarks on UAS missions and general market overview	27
2.1.1. Defense	28
2.1.2. Civil security	29
2.1.3. Civil commercial	29
2.2. Operational specificities of rotary-wing UAS	30
2.3. Examples of civil applications for multi-rotor platform-based UAS	33
2.3.1. Aerial photography	34
2.3.2. Agriculture	35
2.3.3. Avalanche protection	38
2.3.4. Construction and work assistance	38
2.3.5. Linear infrastructure survey	39
2.3.6. Fire fighting	39
2.3.7. Fishing assistance	40
2.3.8. Freight transportation and parcel delivery	40
2.3.9. Industrial site survey	41
2.3.10. Security and police assistance	43
2.3.11. World citizen protection	43
2.3.12. Wildlife protection	44
Chapter 3. UAV System Engineering	45
Sophie LESCURE	
3.1. Introduction to system engineering principles	45
3.1.1. Capability trade-off analysis	45
3.1.2. Functional and non-functional analysis versus requirements	46
3.1.3. Early system design to check requirement feasibility	47
3.2. Operational analysis	47
3.2.1. Operational capabilities needed	49
3.2.2. Functional analysis	51
3.3. Architecture solution design	51
3.4. Deck-landing navigation constraints of VTOL	54
3.5. Navigation chain architecture	56
3.6. Architecture and constraints of the communication system	57
3.6.1. Propagation of signals in free space	57
3.6.2. Propagation of signals in the atmosphere	59

3.7. Human factors	59
3.8. Integration–verification–validation	62
Chapter 4. Large-Scale UAV Trajectory Planning Using Fluid Dynamics Equations	63
Mohammadreza RADMANESH, Kelly COHEN and Manish KUMAR	
4.1. Unmanned air vehicles (UAV) and challenges in their applications	63
4.2. Introduction to path planning and fluid analogy	64
4.2.1. Motion planning and control	64
4.2.2. Optimal path planning and control problem	66
4.2.3. Overview of trajectory planning and the partial differential equation (PDE) approach	66
4.3. Problem formulation	69
4.4. Fluid analogy	70
4.5. Prediction sets (PS)	72
4.6. Governing equations for the centralized approach	75
4.6.1. Governing equations for developing the centralized approach	75
4.6.2. Implementation details and workflow	79
4.7. Numerical results	79
4.7.1. Comparison with the optimal solution.	81
4.8. Conclusion	82
4.9. References	83
Chapter 5. Genetic Fuzzy System for Solving the Aircraft Conflict Resolution Problem	87
Anoop SATHYAN, Nicholas ERNEST, Loïc LAVIGNE, Franck CAZAURANG, Manish KUMAR and Kelly COHEN	
5.1. Introduction.	87
5.2. Problem description	89
5.3. Methodology	91
5.3.1. Five-aircraft problem.	91
5.3.2. Ten-aircraft problem	96
5.4. Results.	96
5.4.1. Five-aircraft problem with $\varepsilon = 1$	97
5.4.2. Five-aircraft problem with $\varepsilon = 2$	98
5.4.3. Ten-aircraft problem with $\varepsilon = 1$	100
5.5. Conclusion and future work	102
5.6. References	102

Chapter 6. Diagnostics and Fault-Tolerant Path Planning 105

César MARTÍNEZ TORRES, Loïc LAVIGNE and Franck CAZAURANG

6.1. Introduction.	105
6.2. Differential flatness	106
6.3. Quadrotor model.	107
6.4. Flatness of the model	112
6.5. Flatness-based fault-tolerant control of a quadrotor UAV	113
6.5.1. Fault detection and isolation	117
6.5.2. Control reconfiguration	122
6.6. Conclusion	125
6.7. References	126

**Chapter 7. LQR Controller Applied to Quadcopter System Dynamics
Identification and Verification Through Frequency Sweeps** 129

Zachary CARLTON, Wei WEI and Kelly COHEN

7.1. Configuration.	130
7.2. Conventions and assumptions	131
7.3. State-space representation	134
7.4. Time-history data collection	136
7.5. Overview of CIPHER®.	137
7.5.1. Non-parameterized model identification	139
7.5.2. Parameterized model identification	140
7.6. Open-loop system identification	141
7.6.1. Heave axis	141
7.6.2. Directional axis	142
7.6.3. Lateral–longitudinal axis	142
7.7. System model verification	145
7.8. LQR controller optimization.	149
7.9. References	151

**Chapter 8. Autonomous Navigation and Target Geo-Location
in GPS Denied Environment** 153

Manish KUMAR, Mohammad SARIM and Alireza NEMATI

8.1. Introduction.	153
8.2. Related works	154
8.3. System architecture	156
8.4. Navigation algorithm	158
8.4.1. Map access.	158
8.4.2. Scan matching.	159

8.4.3. Navigation and obstacle avoidance	159
8.5. Target geo-location	161
8.5.1. Target identification	161
8.5.2. Target localization using triangulation	164
8.6. Quadrotor dynamics	165
8.6.1. Dynamic model	165
8.6.2. Motor control	166
8.6.3. Attitude control	167
8.6.4. Position control	168
8.7. Results	168
8.7.1. Simulation set-up	168
8.7.2. Simulation results	169
8.8. References	172
Chapter 9. Real-Time Video and FLIR Image Processing for Enhanced Situational Awareness	177
Manish KUMAR, Anoop SATHYAN and Kelly COHEN	
9.1. Introduction	177
9.2. Literature review	180
9.3. Methodology	184
9.3.1. Setting up the FLS	185
9.3.2. Training the FLS	192
9.4. Results and discussion	193
9.5. Conclusion and future work	200
9.6. Acknowledgments	200
9.7. References	200
Chapter 10. Design, Fabrication and Flight Tests of Small UAVs Using Additive Manufacturing	203
Nathaniel RICHARDS, Justin OUWERKERK, Bryan BROWN and Kelly COHEN	
10.1. What is 3D printing?	203
10.2. Preliminary design considerations	204
10.3. Motivation for additive manufacturing	205
10.4. Additive manufacturing for design	206
10.4.1. Vesper	206
10.4.2. HEAV	207
10.5. Exotic materials	213
10.6. References	215

Chapter 11. Genetic Fuzzy Single and Collaborative Tasking for UAV Operations	217
Nicholas ERNEST, Anoop SATHYAN and Kelly COHEN	
11.1. Introduction	217
11.2. Problem formulation	224
11.2.1. Assumptions	226
11.3. Methodology	227
11.3.1. Fuzzy clustering method	227
11.3.2. Genetic fuzzy clustering method	228
11.3.3. Genetic fuzzy clustering using an approximate cost function	231
11.4. Results	232
11.5. Conclusion and future work	239
11.6. References	240
List of Authors	243
Index	245