# Table of Contents

**Acknowledgments** ..... ix

**Chapter 1 Introduction** ..... 1

1.1 Background ..... 2
1.2 Scope ..... 2
1.3 Book Structure ..... 3
1.4 References ..... 3

**Chapter 2 Sensors, Instrumentation, and Signal Processing** ..... 5

2.1 Introduction ..... 6
2.2 Overview of Measurement Systems and Components ..... 6
2.3 Sensors and Transducers ..... 7
2.4 Analog-to-Digital Conversion and Associated Issues ..... 10
2.5 Instrumentation Choice for an IVHM System ..... 16
2.6 Feature Extraction Techniques ..... 19
2.7 Case Study—Machine Fault Simulator Unbalance Localization ..... 21
2.8 References ..... 24

**Chapter 3 Data-Driven Anomaly Detection and Diagnosis** ..... 27

3.1 Introduction ..... 28
3.2 System Modeling and Residuals ..... 28
3.3 Machine Learning ..... 29
3.4 Putting It All Together ..... 45
3.5 References ..... 46

**Chapter 4 Prognostics** ..... 49

4.1 Introduction ..... 50
4.2 System Model ..... 51
4.3 Damage Propagation Model ..... 51
4.4 Prognostic Algorithm ..... 51
4.5 Damage Threshold ..... 51
4.6 Prognosis and Uncertainty Characterization ..... 51
4.7 Prognostic Techniques ..... 53
4.8 Measuring Prognostics Performance ..... 57
4.9 Electro-Mechanical Actuator Case Study ..... 59

4.10 Conclusions and Recommendations ..... 68
4.11 References ..... 68

**Chapter 5 IVHM Assessment Metrics ..... 71**

5.1 Measuring IVHM Effectiveness ..... 72
5.2 IVHM Metrics ..... 73
5.3 The Challenge of Data Availability ..... 85
5.4 Conclusions ..... 86
5.5 References ..... 86

**Chapter 6 IVHM Architecture ..... 89**

6.1 Introduction ..... 90
6.2 Background on IVHM and Avionics Systems ..... 91
6.3 Design Guidelines for OCBM ..... 94
6.4 IVHM Functional Architecture ..... 96
6.5 The Avionics Architecture That Includes IVHM ..... 97
6.6 Hardware Technologies That Enable OCBM ..... 98
6.7 Software Architecture That Enables OCBM ..... 102
6.8 On-Ground Network Elements ..... 109
6.9 Summary and Conclusions ..... 111
6.10 References ..... 111

**Chapter 7 Data Management ..... 115**

7.1 Introduction ..... 116
7.2 System Architectures ..... 117
7.3 Data Processing and Fusion ..... 119
7.4 Data Reduction and Compression ..... 126
7.5 Conclusions ..... 136
7.6 References ..... 136

**Chapter 8 Vehicle-Level Reasoning Systems ..... 139**

8.1 Introduction ..... 140
8.2 Background ..... 140
8.3 Defining VLRS ..... 142
8.4 VLRS Architecture ..... 147
8.5 Standards for VLRS ..... 148
8.6 Example: Emerging VLRS Implementation ..... 148
8.7 Economic and Safety Consequences ..... 152
8.8 Conclusions ..... 153
8.9 References ..... 154

**Chapter 9 IVHM System Design ..... 157**

9.1 Introduction ..... 158
9.2 Requirements and Specification Generation ..... 158
9.3 Development of Prognostics Framework ..... 161
9.4 Design Considerations ..... 162
9.5 Testing ..... 170
9.6 Integration ..... 174
9.7 Conclusions ..... 175
9.8 References ..... 175

**Chapter 10 Applications ..... 177**

10.1 Introduction ..... 178
10.2 SHM for Aerospace Applications ..... 178
10.3 Rotating Machinery ..... 193
10.4 The Application of IVHM in Motorsport ..... 201
10.5 Prognostics and Health Management for Wind Turbines ..... 208

**Chapter 11 Disruptive Technologies ..... 235**

11.1 Introduction ..... 236
11.2 Sensor Technologies ..... 236
11.3 Wireless Data Systems ..... 242
11.4 Subsystem Application Technologies ..... 246
11.5 System-Level Technologies ..... 251
11.6 References ..... 255

**Chapter 12 Summary and Concluding Remarks ..... 259**

**Appendix: Acronyms ..... 263**

**Index ..... 269**

**About the Authors ..... 277**