## Contents

### 'Art I  Introduction to Multisensor Data Fusion

1 Multisensor Data Fusion  *David L. Hall and James Llinas*

1.1 Introduction  1-1  
1.2 Multisensor Advantages  1-2  
1.3 Military Applications  1-3  
1.4 Nonmilitary Applications  1-4  
1.5 Three Processing Architectures  1-5  
1.6 A Data Fusion Process Model  1-6  
1.7 Assessment of the State of the Art  1-8  
1.8 Additional Information  1-10  
Reference  1-10

2 Revisions to the JDL Data Fusion Model  *Alan N. Steinberg and Christopher L. Bowman*

2.1 Introduction  2-1  
2.2 What Is Data Fusion? What Isn't?  2-1  
2.3 Models and Architectures  2-4  
2.4 Beyond the Physical  2-12  
2.5 Comparison with Other Models  2-15  
2.6 Summary  2-17  
References  2-18

3 Introduction to the Algorithmics of Data Association in Multiple-Target Tracking  *Jeffrey K. Uhlmann*

3.1 Introduction  3-1  
3.2 Ternary Trees  3-10  
3.3 Priority kd-Trees  3-13  
3.4 Conclusion  3-17  
Acknowledgments  3-17  
References  3-17
Part II Advanced Tracking and Association Methods

8 Target Tracking Using Probabilistic Data Association-Based Techniques with Applications to Sonar, Radar, and EO Sensors T. Kirubarajan and Yaakov Bar-Shalom
8.1 Introduction 8-1
8.2 Probabilistic Data Association 8-2
8.3 Low Observable TMA Using the ML-PDA Approach with Features 8-8
8.4 The IMMPDAF for Tracking Maneuvering Targets 8-17
8.5 A Flexible-Window ML-PDA Estimator for Tracking Low Observable (LO) Targets 8-27
8.6 Summary 8-37
References 8-37

9 An Introduction to the Combinatorics of Optimal and Approximate Data Association Jeffrey K. Uhlmann
9.1 Introduction 9-1
9.2 Background 9-2
9.3 Most Probable Assignments 9-4
9.4 Optimal Approach 9-5
9.5 Computational Considerations 9-7
9.6 Efficient Computation of the JAM 9-8
9.7 Crude Permanent Approximations 9-8
9.8 Approximations Based on Permanent Inequalities 9-10
9.9 Comparisons of Different Approaches 9-12
9.10 Large-Scale Data Associations 9-15
9.11 Generalizations 9-17
9.12 Conclusions 9-17
Acknowledgments 9-18
Appendix 9.A Algorithm for Data Association Experiment 9-18
References 9-19

10 A Bayesian Approach to Multiple-Target Tracking Lawrence D. Stone
10.1 Introduction 10-1
10.2 Bayesian Formulation of the Single-Target Tracking Problem 10-3
10.3 Multiple-Target Tracking without Contacts or Association (Unified Tracking) 10-8
10.4 Multiple-Hypothesis Tracking (MHT) 10-12
10.5 Relationship of Unified Tracking to MHT and Other Tracking Approaches 10-22
10.6 Likelihood Ratio Detection and Tracking 10-23
References 10-30
Part III  Systems Engineering and Implementation

15 Requirements Derivation for Data Fusion Systems  
*Ed Waltz and David L. Hall*

15.1 Introduction 15-1
15.2 Requirements Analysis Process 15-2
15.3 Engineering Flow-Down Approach 15-3
15.4 Enterprise Architecture Approach 15-5
15.5 Comparison of Approaches 15-6
References 15-8

16 A Systems Engineering Approach for Implementing Data Fusion Systems  
*Christopher L. Bowman and Alan N. Steinberg*

16.1 Scope 16-1
16.2 Architecture for Data Fusion 16-2
16.3 Data Fusion System Engineering Process 16-7
16.4 Fusion System Role Optimization 16-17
References 16-38

17 Studies and Analyses with Project Correlation: An In-Depth Assessment of Correlation Problems and Solution Techniques  
*James Llinas, Lori McConnel, Christopher L. Bowman, David L. Hall, and Paul Applegate*

17.1 Introduction 17-1
17.2 A Description of the Data Correlation (DC) Problem 17-3
17.3 Hypothesis Generation 17-4
17.4 Hypothesis Evaluation 17-8
17.5 Hypothesis Selection 17-9
17.6 Summary 17-17
References 17-18

18 Data Management Support to Tactical Data Fusion  
*Richard Antony*

18.1 Introduction 18-1
18.2 Database Management Systems 18-2
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.3</td>
<td>Spatial, Temporal, and Hierarchical Reasoning</td>
<td></td>
<td>18-3</td>
</tr>
<tr>
<td>18.4</td>
<td>Database Design Criteria</td>
<td></td>
<td>18-6</td>
</tr>
<tr>
<td>18.5</td>
<td>Object Representation of Space</td>
<td></td>
<td>18-14</td>
</tr>
<tr>
<td>18.6</td>
<td>Integrated Spatial/Nonspatial Data Representation</td>
<td></td>
<td>18-16</td>
</tr>
<tr>
<td>18.7</td>
<td>Sample Application</td>
<td></td>
<td>18-17</td>
</tr>
<tr>
<td>18.8</td>
<td>Summary and Conclusions</td>
<td></td>
<td>18-25</td>
</tr>
<tr>
<td></td>
<td>Acknowledgments</td>
<td></td>
<td>18-25</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
<td>18-25</td>
</tr>
<tr>
<td>19</td>
<td>Removing the HCI Bottleneck: How the Human-Computer Interface (HCI) Affects the Performance of Data Fusion Systems</td>
<td>Mary Jane M. Hall, Sonya A. Hall, and Timothy Tate</td>
<td>19-1</td>
</tr>
<tr>
<td>19.1</td>
<td>Introduction</td>
<td></td>
<td>19-3</td>
</tr>
<tr>
<td>19.2</td>
<td>A Multimedia Experiment</td>
<td></td>
<td>19-5</td>
</tr>
<tr>
<td>19.3</td>
<td>Summary of Results</td>
<td></td>
<td>19-9</td>
</tr>
<tr>
<td>19.4</td>
<td>Implications for Data Fusion Systems</td>
<td></td>
<td>19-10</td>
</tr>
<tr>
<td></td>
<td>Acknowledgment</td>
<td></td>
<td>19-11</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
<td>19-11</td>
</tr>
<tr>
<td>20</td>
<td>Assessing the Performance of Multisensor Fusion Processes</td>
<td>James Llinas</td>
<td>20-1</td>
</tr>
<tr>
<td>20.1</td>
<td>Introduction</td>
<td></td>
<td>20-3</td>
</tr>
<tr>
<td>20.2</td>
<td>Test and Evaluation of the Data Fusion Process</td>
<td></td>
<td>20-7</td>
</tr>
<tr>
<td>20.3</td>
<td>Tools for Evaluation: Testbeds, Simulations, and Standard Data Sets</td>
<td></td>
<td>20-11</td>
</tr>
<tr>
<td>20.4</td>
<td>Relating Fusion Performance to Military Effectiveness - Measures of Merit</td>
<td></td>
<td>20-17</td>
</tr>
<tr>
<td>20.5</td>
<td>Summary</td>
<td></td>
<td>20-17</td>
</tr>
<tr>
<td></td>
<td>Acknowledgments</td>
<td></td>
<td>20-17</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Dirty Secrets in Multisensor Data Fusion</td>
<td>David L. Hall and Alan N. Steinberg</td>
<td>21-1</td>
</tr>
<tr>
<td>21.1</td>
<td>Introduction</td>
<td></td>
<td>21-2</td>
</tr>
<tr>
<td>21.2</td>
<td>The JDL Data Fusion Process Model</td>
<td></td>
<td>21-7</td>
</tr>
<tr>
<td>21.3</td>
<td>Current Practices and Limitations in Data Fusion</td>
<td></td>
<td>21-9</td>
</tr>
<tr>
<td>21.4</td>
<td>Research Needs</td>
<td></td>
<td>21-10</td>
</tr>
<tr>
<td>21.5</td>
<td>Pitfalls in Data Fusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21.6</td>
<td>Summary</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acknowledgments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part IV</td>
<td>Sample Applications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>A Survey of Multisensor Data Fusion Systems</td>
<td>Mary L. Nichols</td>
<td>22-1</td>
</tr>
<tr>
<td>22.1</td>
<td>Introduction</td>
<td></td>
<td>22-1</td>
</tr>
<tr>
<td>22.2</td>
<td>Recent Survey of Data Fusion Activities</td>
<td></td>
<td>22-2</td>
</tr>
<tr>
<td>22.3</td>
<td>Assessment of System Capabilities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
23 Data Fusion for Developing Predictive Diagnostics for Electromechanical Systems  *Carl S. Byington and Amulya K. Garga*

23.1 Introduction  23-1
23.2 Aspects of a CBM System  23-3
23.3 The Diagnosis Problem  23-4
23.4 Multisensor Fusion Toolkit  23-7
23.5 Application Examples  23-8
23.6 Concluding Remarks  23-29
Acknowledgments  23-30
References  23-30

24 Information Technology for NASA in the 21st Century  *Robert J. Hansen, Daniel Cooke, Kenneth Ford, and Steven Zornetzer*

24.1 Introduction  24-1
24.2 NASA Applications  24-2
24.3 Critical Research Investment Areas for NASA  24-3
24.4 High-Performance Computing and Networking  24-5
24.5 Conclusions  24-6

25 Data Fusion for a Distributed Ground-Based Sensing System  *Richard R. Brooks*

25.1 Introduction  25-1
25.2 Problem Domain  25-2
25.3 Existing Systems  25-3
25.4 Prototype Sensors for SenseIT  25-4
25.5 Software Architecture  25-5
25.6 Declarative Language Front-End  25-6
25.7 Subscriptions  25-6
25.8 Mobile Code  25-7
25.9 Diffusion Network Routing  25-7
25.10 Collaborative Signal Processing  25-7
25.11 Information Security  25-8
25.12 Summary  25-8
Acknowledgments and Disclaimers  25-8
References  25-8

26 An Evaluation Methodology for Fusion Processes Based on Information Needs  *Hans Keithley*

26.1 Introduction  26-1
26.2 Information Needs  26-2
26.3 Key Concept  26-6
Part V Resources

Web Sites and News Groups Related to Data Fusion

Data Fusion Web Sites
News Groups
Other World Wide Web Information
Government Laboratories and Agencies

Index