Electro-Optical Systems Design, Analysis, and Testing

Volume 4

The Infrared and Electro-Optical Systems Handbook
The Infrared and Electro-Optical Systems Handbook

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Chapter 3. Optomechanical System Design, Daniel Vukobratovich
Chapter 4. Infrared Imaging System Testing, Gerald C. Holst
Chapter 5. Tracking and Control Systems, Robert E. Nasburg
Chapter 6. Signature Prediction and Modeling, John A. Conant, Malcolm A. LeCompte

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Electro-Optical Systems Design, Analysis, and Testing

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Preface

The Infrared and Electro-Optical Systems Handbook is a joint product of the Infrared Information Analysis Center (IRIA) and the International Society for Optical Engineering (SPIE). Sponsored by the Defense Technical Information Center (DTIC), this work is an outgrowth of its predecessor, The Infrared Handbook, published in 1978. The circulation of nearly 20,000 copies is adequate testimony to its wide acceptance in the electro-optics and infrared communities. The Infrared Handbook was itself preceded by The Handbook of Military Infrared Technology. Since its original inception, new topics and technologies have emerged for which little or no reference material exists. This work is intended to update and complement the current Infrared Handbook by revision, addition of new materials, and reformatting to increase its utility. Of necessity, some material from the current book was reproduced as is, having been adjudged as being current and adequate. The 45 chapters represent most subject areas of current activity in the military, aerospace, and civilian communities and contain material that has rarely appeared so extensively in the open literature.

Because the contents are in part derivatives of advanced military technology, it seemed reasonable to categorize those chapters dealing with systems in analogy to the specialty groups comprising the annual Infrared Information Symposia (IRIS), a Department of Defense (DoD) sponsored forum administered by the Infrared Information Analysis Center of the Environmental Research Institute of Michigan (ERIM); thus, the presence of chapters on active, passive, and countermeasure systems.

There appears to be no general agreement on what format constitutes a “handbook.” The term has been applied to a number of reference works with markedly different presentation styles ranging from data compendiums to tutorials. In the process of organizing this book, we were obliged to embrace a style of our choosing that best seemed to satisfy the objectives of the book: to provide derivational material data, descriptions, equations, procedures, and examples that will enable an investigator with a basic engineering and science education, but not necessarily an extensive background in the specific technology, to solve the types of problems he or she will encounter in design and analysis of electro-optical systems. Usability was the prime consideration. In addition, we wanted each chapter to be largely self-contained to avoid time-consuming and tedious referrals to other chapters. Although best addressed by example, the essence of our handbook style embodies four essential ingredients: a brief but well-referenced tutorial, a practical formulary, pertinent data, and, finally, example problems illustrating the use of the formulary and data.
The final product represents varying degrees of success in achieving this structure, with some chapters being quite successful in meeting our objectives and others following a somewhat different organization. Suffice it to say that the practical exigencies of organizing and producing a compendium of this magnitude necessitated some compromises and latitude. Its ultimate success will be judged by the community that it serves. Although largely oriented toward system applications, a good measure of this book concentrates on topics endemic and fundamental to systems performance. It is organized into eight volumes:

Volume 1, edited by George Zissis of ERIM, treats sources of radiation, including both artificial and natural sources, the latter of which in most military applications is generally regarded as background radiation.

Volume 2, edited by Fred Smith of OptiMetrics, Inc., treats the propagation of radiation. It features significant amounts of new material and data on absorption, scattering, and turbulence, including nonlinear propagation relevant to high-energy laser systems and propagation through aerodynamically induced flow relevant to systems mounted on high-performance aircraft.

Volume 3, edited by William Rogatto of Santa Barbara Research Center, treats traditional system components and devices and includes recent material on focal plane array read-out electronics.

Volume 4, edited by Michael Dudzik of ERIM, treats system design, analysis, and testing, including adjunct technology and methods such as trackers, mechanical design considerations, and signature modeling.

Volume 5, edited by Stephen Campana of the Naval Air Warfare Center, treats contemporary infrared passive systems such as FLIRs, IRSTs, IR line scanners, and staring array configurations.

Volume 6, edited by Clifton Fox of the Night Vision and Electronic Sensors Directorate, treats active systems and includes mostly new material on laser radar, laser rangefinders, millimeter-wave systems, and fiber optic systems.

Volume 7, edited by David Pollock, consultant, treats a number of countermeasure topics rarely appearing in the open literature.

Volume 8, edited by Stanley Robinson of ERIM, treats emerging technologies such as unconventional imaging, synthetic arrays, sensor and data fusion, adaptive optics, and automatic target recognition.

Acknowledgments

It is extremely difficult to give credit to all the people and organizations that contributed to this project in diverse ways. A significant amount of material in this book was generated by the sheer dedication and professionalism of many esteemed members of the IR and EO community who unselfishly contributed extensive amounts of precious personal time to this effort and to whom the modest honorarium extended was scarcely an inducement. Their contributions speak elegantly of their skills.
Directly involved were some 85 authors and editors from numerous organizations, as well as scores of technical reviewers, copyeditors, graphic artists, and photographers whose skill contributed immeasurably to the final product.

We acknowledge the extensive material and moral support given to this project by various members of the managements of all the sponsoring and supporting organizations. In many cases, organizations donated staff time and internal resources to the preparation of this book. Specifically, we would like to acknowledge J. MacCallum of DoD, W. Brown and J. Walker of ERIM, and J. Yaver of SPIE, who had the foresight and confidence to invest significant resources in the preparation of this book. We also extend our appreciation to P. Klinefelter, B. McCabe, and F. Frank of DTIC for their administrative support during the course of this program.

Supporting ERIM staff included Ivan Clemons, Jenni Cook, Tim Kellman, Lisa Lyons, Judy Steeh, Barbara Wood, and the members of their respective organizations that contributed to this project.

We acknowledge Lorretta Palagi and the publications staff at SPIE for a professional approach to the truly monumental task of transforming the manuscripts into presentable copy and the patience required to interact effectively with the authors.

We would like to pay special tribute to Nancy Hall of the IRIA Center at ERIM who administrated this at times chaotic project with considerable interpersonal skill, marshaling the numerous manuscripts and coordinating the myriad details characteristic of a work of this magnitude.

We properly dedicate this book to the people who created it and trust it will stand as a monument to their skills, experience, and dedication. It is, in the final analysis, a product of the community it is intended to serve.

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David L. Shumaker
Ann Arbor, Michigan

January 1993
Notices and Disclaimer

This handbook was prepared by the Infrared Information Analysis Center (IRIA) in cooperation with the International Society for Optical Engineering (SPIE). The IRIA Center, Environmental Research Institute of Michigan, is a Defense Technical Information Center-sponsored activity under contract DLA-800-C-393 and administrated by the Defense Electronics Supply Center, Defense Logistics Agency.

This work relates to the aforementioned ERIM contract and is in part sponsored by the Department of Defense; however, the contents do not necessarily reflect the position or the policy of the Department of Defense or the United States government and no official endorsement should be inferred.

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The information in this handbook is judged to be from the best available sources; however, the authors, editors, Department of Defense or any of its agencies, the Environmental Research Institute of Michigan, or the International Society for Optical Engineering do not assume any liability for the validity of the information contained herein or for any consequence of its use.
Contents

Introduction xiii

CHAPTER 1 Fundamentals of Electro-Optical Imaging Systems Analysis, J. M. Lloyd
1.1 Introduction 3
1.2 Photon Collection and Signal-to-Noise Ratio 11
1.3 Clutter Noise 32
1.4 Spatial Frequency Response 35
1.5 Sampling and Aliasing 44
1.6 Visual Detection of Noisy Signals 48
1.7 Application to System Design 49

CHAPTER 2 Electro-Optical Imaging System Performance Prediction, James D. Howe
2.1 Introduction 57
2.2 The Elements of Target Acquisition 60
2.3 The Imaging Chain 63
2.4 System Performance Measures 77
2.5 Static Performance Prediction 83
2.6 Search Performance Modeling 106

CHAPTER 3 Optomechanical System Design, Daniel Vukobratovich
3.1 Introduction 123
3.2 Windows 123
3.3 Prisms 136
3.4 Lens Mounting 140
3.5 Lens Barrels 150
3.6 Mirror Design and Mounting 156
3.7 Athermalization 177
3.8 Example Problems 183
CHAPTER 4  Infrared Imaging System Testing, Gerald C. Holst
  4.1 Introduction 197
  4.2 Test Philosophy 202
  4.3 Radiometry and the $\Delta T$ Concept 203
  4.4 Test Configurations 206
  4.5 Signal Transfer Function 209
  4.6 Three-Dimensional Noise Model 212
  4.7 Slit Response Function 221
  4.8 Modulation Transfer Function 223
  4.9 Contrast Transfer Function 232
  4.10 Minimum Resolvable Temperature 235

CHAPTER 5  Tracking and Control Systems, Robert E. Nasburg
  5.1 Introduction 247
  5.2 Target Location Estimation 254
  5.3 Target Gating and Breaklock Detection 280
  5.4 LOS Determination and Track Loop Compensation 289
  5.5 Track Loop Performance Prediction 292

CHAPTER 6  Signature Prediction and Modeling, John A. Conant,
            Malcolm A. LeCompte
  6.1 Introduction 301
  6.2 Observable Intensity Relations 303
  6.3 Geometry Description 306
  6.4 Simplified Radiation Environment Model 313
  6.5 Simplified BRDF/Emissivity Model 318
  6.6 Body Temperatures 320
  6.7 Opaque Surface Reflections and Emissions 323
  6.8 Engine Exhaust Plumes 329
  6.9 Summary 340

Index 343
Introduction

This volume is devoted to the design, analysis, and testing methodologies of electro-optical systems. Specifically, the volume describes the image chain process used in sensor development. This volume is intended for scientists and engineers who desire a working knowledge of the principles, models, and practice of electro-optical sensor development. The volume contains information that is supplemented with relevant data, illustrative examples, and supporting references.

Although the primary thrust of this volume is devoted to imaging sensors, much of the information is relevant to other imaging and nonimaging sensor systems. The growing use of electro-optical sensors in military and commercial applications is being used to address a wide range of unique sensing problems. While the sensing problems are various, the physical principles of sensor development are similar. This volume was prepared to address those common areas of sensor development.

The volume is made up of six chapters. Chapter 1 by J. Michael Lloyd is an introduction to electro-optical imaging systems, with special emphasis on thermal imaging sensor systems. This includes a systems engineering approach to understanding source, sensor, and image scene characteristics. Central to this chapter is the application of optical transfer function theory to describe sensor response to various input functions. This chapter provides the tools to make first-order estimates of the theoretical limits of sensor resolution, frequency response and noise-limited performance of imaging sensors, SNR and resolution criteria, and scene clutter strengths relative to signal sources.

Chapter 2 by James Howe is an introduction to the fundamentals of electro-optical imaging systems performance prediction. This chapter provides a detailed description of the parameters of performance associated with detection, recognition, and identification for first- and second-generation imaging sensors. Howe’s chapter continues the system engineering approach to sensor development and provides a detailed analysis on the information content of the scene image produced by the sensor system. Of note is the development of the methodology to understand the uses and limitations of first- and second-generation thermal imaging system performance models.

Chapter 3 by Daniel Vukobratovich provides theory and practical data on the application of optomechanical systems design to electro-optical sensors. This chapter treats many of the practical implementation problems associated with the design of electro-optical windows, lens housings, and structural features. This chapter is a natural progression of the sensor system design process to assist the design staff in creating actual sensor designs to meet the performance characteristics envisioned by the systems engineer. Of concern to all system
developers is the mounting of optical elements to ensure optical performance against thermal and pressure effects.

Chapter 4 by Gerald Holst is an introduction to electro-optical system testing and performance evaluation. This chapter provides the methodology and procedures for establishing many of the sensor performance measures used in imaging electro-optical sensors. In addition, Holst provides insight into the practical problems associated with optical collimator, test equipment, and electronic measurements. This chapter complements the image chain analysis by allowing the systems engineer to evaluate the results of actual hardware testing on theoretical design criteria.

Chapter 5 by Robert Nasburg provides discussions on the theory and application of tracking and control systems. With the ever-increasing demand for image processing of sensor information, Nasburg provides a systems engineering approach to sensor-derived information applications. This chapter allows the systems designer to develop an understanding of the information processing requirements placed upon the sensor output. This is especially important in those electro-optical sensors in which preprocessing or prefiltering of scene information occurs before being presented to a human operator for display.

Chapter 6 by John Conant and Malcom LeCompte is an introduction to signature modeling. This chapter provides a practical methodology to develop a first-order estimate of both emitted and reflected radiation from a complex target shape. The technical approach allows the systems developer to approximate the performance of an electro-optical sensor against a new or different target class or in a different application. The chapter further serves as a practical illustration of the physical phenomena inherent to the generation of electro-optical signatures.

This volume of course could not have been assembled without the technical contributions of my many colleagues and fellow workers in the field of electro-optics. I am gratefully indebted to the following individuals for their assistance during the preparation of this volume: H. Kennedy, D. Ratcliff, M. Michel, T. Milson, G. Zissis, J. Accetta, G. Nado, and D. Ausherman. Also, I would like to thank Ms. Nancy Hall of ERIM for her patience in the preparation and coordination of the manuscripts. Finally, I wish to thank my family, Katherine and Michael Dudzik, for allowing me the time necessary to complete this volume.

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