Practical Applications of Infrared Thermal Sensing and Imaging Equipment

Third Edition

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Herbert Kaplan

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Introduction to the Series

Since its conception in 1989, the Tutorial Texts series has grown to more than 70 titles covering many diverse fields of science and engineering. When the series was started, the goal of the series was to provide a way to make the material presented in SPIE short courses available to those who could not attend, and to provide a reference text for those who could. Many of the texts in this series are generated from notes that were presented during these short courses. But as stand-alone documents, short course notes do not generally serve the student or reader well. Short course notes typically are developed on the assumption that supporting material will be presented verbally to complement the notes, which are generally written in summary form to highlight key technical topics and therefore are not intended as stand-alone documents. Additionally, the figures, tables, and other graphically formatted information accompanying the notes require the further explanation given during the instructor's lecture. Thus, by adding the appropriate detail presented during the lecture, the course material can be read and used independently in a tutorial fashion.

What separates the books in this series from other technical monographs and textbooks is the way in which the material is presented. To keep in line with the tutorial nature of the series, many of the topics presented in these texts are followed by detailed examples that further explain the concepts presented. Many pictures and illustrations are included with each text and, where appropriate, tabular reference data are also included.

The topics within the series have grown from the initial areas of geometrical optics, optical detectors, and image processing to include the emerging fields of nanotechnology, biomedical optics, and micromachining. When a proposal for a text is received, each proposal is evaluated to determine the relevance of the proposed topic. This initial reviewing process has been very helpful to authors in identifying, early in the writing process, the need for additional material or other changes in approach that would serve to strengthen the text. Once a manuscript is completed, it is peer reviewed to ensure that chapters communicate accurately the essential ingredients of the processes and technologies under discussion.

It is my goal to maintain the style and quality of books in the series, and to further expand the topic areas to include new emerging fields as they become of interest to our reading audience.

Arthur R. Weeks, Jr.
University of Central Florida

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List of Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Test and Measurement
BCD	binary coded decimal
BST	barium–strontium–titanate
dc emf	direct current electromagnetic force
emf	electromagnetic force
EPRI	Electric Power Research Institute
FLIR	forward-looking infrared
FOV	field of view
FPA	focal plane array
HRSG	heat recovery steam generator
IFOV	instantaneous field of view
IFOVmeas or MFOV	measurement IFOV or measurement spatial resolution
IR	infrared
IRFPA	infrared focal plane array
IRNDT	infrared nondestructive testing
IVD	intervertebral disk disease
LWIR	long-wave infrared region
MFOV	*see* IFOVmeas
MRT	minimum resolvable temperature
MRTD	minimum resolvable temperature difference
MTF	modulation transfer function
MWIR	mid-wave infrared region
NDE	nondestructive evaluation
NEI	noise equivalent irradiance
NETD	noise equivalent temperature difference
NIR	near infrared
NIST	National Institute of Standards and Technology (U.S.)
P	proportional

PCMCIA	Personal Computer Memory Card International Association
PI	proportional plus integral
PID	proportional plus integral plus differential
QWIP	quantum well infrared photodetector
SRF	slit response function
SWIR	short-wave infrared region
TE	thermoelectric
TFOV	total field of view
TLV	thermal light valve
TRIR	time-resolved infrared radiometry
TSR	thermographic signal reconstruction
VDC	volts DC

Preface

The mapping of infrared (IR) energy radiated from the surface of natural and manufactured objects makes it possible to detect and recognize objects in the dark and under adverse weather and atmospheric conditions. Quantification of this energy allows users (thermographers) to determine the temperature and thermal behavior of objects.

Infrared thermal sensing and imaging instruments make it possible to measure and map surface temperature and thermal distribution passively and nonintrusively. In addition to the passive measurement of temperature distribution, thermographers have learned to use active or "thermal injection" techniques to study and evaluate the structural integrity of materials and fabricated bonds.

The purposes of this text are:

- To familiarize potential users of commercial IR sensing and imaging instruments with IR measurement and analysis basics;
- To provide the practical information needed for users to select the instrument most appropriate for their application;
- To describe how to perform valid and successful measurements in a variety of applications;
- To serve as a reference to help thermographers examine the validity of new applications.

This text is presented in two parts.

Part I begins with a review of temperature, heat, and heat transfer, with emphasis on radiative heat transfer and its relationship to IR radiation and measurement basics. Physical laws (equations) are presented in terms of their practical importance to the measurement mission.

This is followed by a review and discussion of the characteristics and performance parameters of IR sensing and imaging instruments, including a review of thermal imaging diagnostic software. A discussion of equipment operation follows, including guidelines for making successful measurements.

Part I concludes with a section on training and training programs, highlighting the importance of formal operator training and certification.

What's New?

The second edition of this text was published in 1999, and since that time many improvements have taken place in instrumentation performance and versatility. For example, the almost total replacement of opto-mechanically scanned imagers with focal plane array (FPA)-based "staring" imagers has reduced the size, increased the ruggedness, and improved the spatial resolution of IR cameras, all of which have changed thermographers' expectations of camera performance.

Thus, this third edition reviews these many changes and how they impact the way thermographers operate, deploy, calibrate, and test the new instruments. In addition, the instruments that have been made essentially obsolete are reviewed as part of the historical evolution of the technology.

Part II introduces typical applications for thermal sensing and imaging instruments. Several chapters present various applications areas and discuss typical solutions to measurement problems.

The applications are grouped into logical categories following the guidelines established by SPIE's evolving Thermosense series of meetings, held annually since 1978.

In an attempt to classify these applications into logical categories by industry and discipline, the Thermosense symposia usually devote at least one session to each of the following categories:

1. Plant Condition Monitoring and Predictive Maintenance
2. Buildings and Infrastructure
3. Materials Evaluation – Infrared Nondestructive Testing
4. Process Monitoring and Control
5. Night Vision, Security, and Surveillance
6. Life Sciences Thermography
7. Research and Development (R&D)

The first six classifications are self-explanatory; the seventh is a catch-all to include the introduction of new instrumentation or experimental techniques. Papers on subjects classified as "R&D" one year will often be included in one of the other classifications in subsequent years as the instrumentation or techniques mature. Although these classifications have evolved somewhat over the years, they represent reasonable subdivisions. Therefore, the chapters in Part II are organized in general accordance with these classifications.

To assist the user in instrument selection, Appendix A contains a tabulation of currently available instruments by category and manufacturer, including a digest of performance characteristics and features. Appendix B is a current index of manufacturers' websites, addresses, and phone numbers.

The text also includes quick reference charts and tables to aid the user in on-site measurements (Appendix C) and a glossary of IR/thermography terms (Appendix D).

I would like to acknowledge the contributions of the following organizations for providing data and background for this text:

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Boynton Beach, Florida
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