Practical Applications of Infrared Thermal Sensing and Imaging Equipment

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• Infrared Optics and Zoom Lenses, Allen Mann, Vol. TT42
• Introduction to Adaptive Optics, Robert K. Tyson, Vol. TT41
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Practical Applications of Infrared Thermal Sensing and Imaging Equipment

Third Edition

Herbert Kaplan

Tutorial Texts in Optical Engineering
Volume TT75

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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
## Contents

List of Figures xiii  
List of Tables xvii  
List of Acronyms and Abbreviations xix  
Preface xxi  

**Part I: Basics and Instrument Overview**

### Chapter 1 Introduction 3  
1.1 Overview of This Text 3  
1.2 Reasons for Using IR Instruments 3  
1.3 Advantages of Noncontact Thermal Measurement 4  
1.4 Some Historical Background 5  
1.5 Evolution of IR Cameras 6  

### Chapter 2 Basics of Noncontact Thermal Measurements 9  
2.1 Heat Transfer and Radiation Exchange Basics 9  
2.1.1 Heat and temperature 9  
2.1.2 Converting temperature units 9  
2.1.3 Three modes of heat transfer 10  
2.1.4 Conduction 10  
2.1.5 Convection 11  
2.1.6 Radiation 12  
2.1.7 Radiation exchange at the target surface 13  
2.1.8 Specular and diffuse surfaces 14  
2.1.9 Transient heat exchange 14  
2.2 Infrared Measurement Problem 15  
2.2.1 Noncontact thermal measurements 16  
2.2.2 Target surface 16  
2.2.3 Transmitting medium 20  
2.2.4 Measuring instrument 22  
2.3 Thermal Scanning and Imaging Instruments 25  
2.3.1 Line scanning 25  
2.3.2 Two-dimensional opto-mechanical scanning 26
2.3.3 Infrared focal plane array (IRFPA) cameras 27
2.3.4 IRFPA detectors 28
2.3.5 Pyroelectric vidicon thermal imagers 29

Chapter 3 Matching the Instrument to the Application 33
3.1 Radiation Thermometers (Point-Sensing Instruments) 33
3.2 Infrared Cameras—Qualitative and Quantitative 37
  3.2.1 Performance parameters of quantitative cameras 39
    3.2.1.1 Total field of view (TFOV) and instantaneous field of view (IFOV) 40
    3.2.1.2 Temperature sensitivity: MRTD or MRT 40
    3.2.1.3 Imaging spatial resolution and instantaneous FOV 41
    3.2.1.4 Measurement spatial resolution (IFOVmeas or MFOV) for opto-mechanically scanned imagers 43
    3.2.1.5 Measurement spatial resolution (IFOVmeas or MFOV) for FPA imagers 45
    3.2.1.6 Speed of response and frame repetition rate 45
  3.2.2 Performance parameters of qualitative cameras 46
3.3 Thermal Imaging Software 46
3.4 Thermal Image Fusion Techniques 48

Chapter 4 Instruments Overview 49
4.1 Introduction and Classification of Instruments 49
4.2 Instrument Manufacturers 50
4.3 Discussion of Instruments 50
  4.3.1 Point sensors (radiation thermometers) 50
    4.3.1.1 Infrared thermocouples and probes 50
    4.3.1.2 Portable hand-held instruments 51
    4.3.1.3 On-line monitoring and control 52
    4.3.1.4 Special instruments 52
  4.3.2 Line scanners 53
  4.3.3 Infrared cameras (thermal imagers) 54
    4.3.3.1 Cameras, nonmeasuring (thermal viewers) 54
    4.3.3.2 Cameras, measuring (thermographic imagers) 55
    4.3.3.3 Performance comparisons of FPA measuring cameras 56
  4.4 Thermal Imaging Diagnostic Software 57
    4.4.1 Quantitative thermal measurements of targets 58
    4.4.2 Detailed processing and image diagnostics 59
    4.4.3 Image recording, storage, and recovery 59
    4.4.4 Image comparison 60
    4.4.5 Thermal image fusion 60
    4.4.6 Report and database preparation 61
Chapter 5 Using IR Sensing and Imaging Instruments 63

5.1 Introduction: The Thermal Behavior of the Target 63
5.1.1 Emissivity difference 64
5.1.2 Reflectance difference 64
5.1.3 Transmittance difference 64
5.1.4 Geometric difference 64
5.1.5 Mass transport difference 65
5.1.6 Phase-change difference 65
5.1.7 Thermal capacitance difference 65
5.1.8 Induced heating difference 65
5.1.9 Energy conversion difference 65
5.1.10 Direct heat transfer difference 65
5.1.11 Learning about the target environment 66

5.2 Preparation of Equipment for Operation 66
5.2.1 Calibration and radiation reference sources 66
5.2.1.1 Checking calibration 67
5.2.1.2 Transfer calibration 67
5.2.2 Equipment checklist 68
5.2.3 Equipment checkout and calibration 68
5.2.4 Batteries 68

5.3 Avoiding Common Mistakes in Instrument Operation 68
5.3.1 Start-up procedure 69
5.3.2 Memorizing the default values 69
5.3.3 Setting the correct emissivity 69
5.3.4 Filling the IFOVmeas for accurate temperature measurements 70
5.3.5 Aiming normal to the target surface 71
5.3.6 Recognizing and avoiding reflections from external sources 71
5.3.7 Avoiding radiant heat damage to the instrument 72
5.3.8 Using IR transmitting windows 72

5.4 The Importance of Operator Training 72
5.4.1 Training programs and certification 72

Part II: Instrument Applications

Chapter 6 Introduction to Applications 77

Chapter 7 Plant Condition Monitoring and Predictive Maintenance 79
7.1 Introduction 79
7.2 Electrical Findings 80
7.2.1 High electrical resistance 80
7.2.2 Short circuits 80
Chapter 11  Night Vision, Security, and Surveillance 117
  11.1  Introduction 117
  11.2  Comparing Thermal Imagers with Image Intensifiers 118
  11.3  Homeland Security and other Nonmilitary Applications 118
      11.3.1  Aerial-, ground-, and sea-based search and rescue 118
      11.3.2  Firefighting and first response 118
      11.3.3  Space and airborne reconnaissance 119
      11.3.4  Police surveillance and crime detection and security 119
      11.3.5  Driver’s aid night vision 120
      11.3.6  New thermal image fusion applications 121
      11.3.7  New military applications 121

Chapter 12  Life Sciences Thermography 123
  12.1  Introduction 123
  12.2  Thermography as a Diagnostic Aid in the Early Detection
       of Breast Cancer 123
  12.3  Veterinary Medicine 124
  12.4  Biological and Threat Assessment Applications 124

Appendix A  Commercial Instrument Performance Characteristics 127
Appendix B  Manufacturers of IR Sensing and Imaging Instruments 145
Appendix C  Table of Generic Normal Emissivities of Materials 149
Appendix D  A Glossary of Terms for the Infrared Thermographer 155
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Conductive heat flow</td>
<td>11</td>
</tr>
<tr>
<td>2.2</td>
<td>Convective heat flow</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td>Infrared in the electromagnetic spectrum</td>
<td>13</td>
</tr>
<tr>
<td>2.4</td>
<td>Radiative heat flow</td>
<td>13</td>
</tr>
<tr>
<td>2.5</td>
<td>Radiation impinging on a surface</td>
<td>14</td>
</tr>
<tr>
<td>2.6</td>
<td>Three sets of characteristics in making IR measurements</td>
<td>17</td>
</tr>
<tr>
<td>2.7</td>
<td>Blackbody curves at various temperatures</td>
<td>17</td>
</tr>
<tr>
<td>2.8</td>
<td>Spectral distributions of a blackbody, graybody, and non-graybody</td>
<td>19</td>
</tr>
<tr>
<td>2.9</td>
<td>Components of energy reaching the measuring instrument</td>
<td>19</td>
</tr>
<tr>
<td>2.10</td>
<td>Aiming the instrument to avoid point reflections</td>
<td>20</td>
</tr>
<tr>
<td>2.11</td>
<td>Infrared atmospheric transmission for a 10-meter path at sea level (50% relative humidity)</td>
<td>21</td>
</tr>
<tr>
<td>2.12</td>
<td>Spectral characteristics of glass samples (percent transmission, absorption, and reflectance)</td>
<td>21</td>
</tr>
<tr>
<td>2.13</td>
<td>Transmission of IR transmitting materials</td>
<td>22</td>
</tr>
<tr>
<td>2.14</td>
<td>Components of an IR radiation thermometer</td>
<td>23</td>
</tr>
<tr>
<td>2.15</td>
<td>Typical IR radiation thermometer schematic</td>
<td>24</td>
</tr>
<tr>
<td>2.16</td>
<td>Response curves of various IR detectors</td>
<td>25</td>
</tr>
<tr>
<td>2.17</td>
<td>(a) The addition of a scanning element to a radiation thermometer for single line scanning. (b) Eliminating the scanning element – the substitution of a linear FPA detector for the single element detector</td>
<td>26</td>
</tr>
<tr>
<td>2.18</td>
<td>Infrared line scanner schematic and scanner operation</td>
<td>27</td>
</tr>
<tr>
<td>2.19</td>
<td>Infrared opto-mechanical scanning imager</td>
<td>27</td>
</tr>
<tr>
<td>2.20</td>
<td>Infrared focal plane array camera schematic</td>
<td>28</td>
</tr>
<tr>
<td>2.21</td>
<td>Pyrovidicon camera tube schematic</td>
<td>29</td>
</tr>
<tr>
<td>3.1</td>
<td>Instrument speed of response and time constant</td>
<td>34</td>
</tr>
<tr>
<td>3.2</td>
<td>Instrument FOV determination</td>
<td>35</td>
</tr>
<tr>
<td>3.3</td>
<td>Fields of view of IR radiation thermometers</td>
<td>36</td>
</tr>
<tr>
<td>3.4</td>
<td>Measuring temperature of polyethylene</td>
<td>38</td>
</tr>
<tr>
<td>3.5</td>
<td>Measuring temperature of polyester</td>
<td>38</td>
</tr>
<tr>
<td>3.6</td>
<td>TFOV and IFOV of an IR camera</td>
<td>41</td>
</tr>
</tbody>
</table>
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.7</td>
<td>Test setup for MRTD measurement and MRTD curve</td>
<td>42</td>
</tr>
<tr>
<td>3.8</td>
<td>Test setup for MTF measurement</td>
<td>42</td>
</tr>
<tr>
<td>3.9</td>
<td>MRTD and MTF for a system rated at 1 mrad</td>
<td>44</td>
</tr>
<tr>
<td>3.10</td>
<td>Test setup for slit response function</td>
<td>44</td>
</tr>
<tr>
<td>3.11</td>
<td>Hole response method for determination of IFOVmeas (MFOV) for FPA-based cameras</td>
<td>45</td>
</tr>
<tr>
<td>3.12</td>
<td>Plot of hole response function for an FPA-based camera where MFOV is measured at 8.2 mrad</td>
<td>46</td>
</tr>
<tr>
<td>5.1</td>
<td>Measuring target effective emissivity</td>
<td>70</td>
</tr>
<tr>
<td>5.2</td>
<td>Quick calculation for target spot size and IFOV calculation</td>
<td>71</td>
</tr>
<tr>
<td>7.1</td>
<td>Excessive heating of a connecting clip due to deterioration</td>
<td>81</td>
</tr>
<tr>
<td>7.2</td>
<td>Overheating at a switchyard disconnect due to high contact resistance</td>
<td>81</td>
</tr>
<tr>
<td>7.3</td>
<td>Disastrous failure of leaking isolator</td>
<td>82</td>
</tr>
<tr>
<td>7.4</td>
<td>Fusion of a visible and thermal image of a complex electrical panel</td>
<td>83</td>
</tr>
<tr>
<td>7.5</td>
<td>Overheated pump motor at right caused by lubricant deterioration</td>
<td>86</td>
</tr>
<tr>
<td>7.6</td>
<td>Abnormally functioning steam trap shown on the left side</td>
<td>87</td>
</tr>
<tr>
<td>7.7</td>
<td>Gas leak in valve appears as a black cloud on the thermogram</td>
<td>89</td>
</tr>
<tr>
<td>7.8</td>
<td>Leaking seal in a joint between a gas turbine and a steam boiler</td>
<td>90</td>
</tr>
<tr>
<td>8.1</td>
<td>Thermogram of a building showing the effects of air exfiltration</td>
<td>92</td>
</tr>
<tr>
<td>8.2</td>
<td>Thermogram of a building showing the effects of insulation deficiencies</td>
<td>93</td>
</tr>
<tr>
<td>8.3</td>
<td>Thermogram of a roof with moisture saturation</td>
<td>95</td>
</tr>
<tr>
<td>8.4</td>
<td>Roof thermogram with heated interior showing insulation differences and no water saturation</td>
<td>95</td>
</tr>
<tr>
<td>8.5</td>
<td>Photo and thermogram of a radiantly heated floor</td>
<td>95</td>
</tr>
<tr>
<td>8.6</td>
<td>Insulation void on visibly featureless wall is pinpointed using thermal image fusion</td>
<td>96</td>
</tr>
<tr>
<td>9.1</td>
<td>Example of steady-state, active (heat injection) IRNDT for occlusion and void detection</td>
<td>99</td>
</tr>
<tr>
<td>9.2</td>
<td>Three-view thermogram of a cable section with electrical current used as the active heat source</td>
<td>100</td>
</tr>
<tr>
<td>9.3</td>
<td>Basis for time-resolved IR radiometry (TRIR)</td>
<td>101</td>
</tr>
<tr>
<td>9.4</td>
<td>Configuration for pulsed thermography</td>
<td>103</td>
</tr>
<tr>
<td>9.5</td>
<td>Examples of IRNDT images using thermal wave injection—see text for descriptions</td>
<td>104</td>
</tr>
<tr>
<td>9.6</td>
<td>Results of thermal image reconstruction on a graphite epoxy sample</td>
<td>104</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>9.7</td>
<td>In-situ thermogram of a boiler tube section indicating areas of thinning due to corrosion</td>
<td>105</td>
</tr>
<tr>
<td>9.8</td>
<td>Thermogram of a new section of boiler tubing not yet put into service—no thinning indicated</td>
<td>105</td>
</tr>
<tr>
<td>10.1</td>
<td>Three methods of accomplishing process control</td>
<td>108</td>
</tr>
<tr>
<td>10.2</td>
<td>Typical configuration for multisensor process control</td>
<td>108</td>
</tr>
<tr>
<td>10.3</td>
<td>Electrolytic tankhouse scan where interelectrode shorts appear as hot spots</td>
<td>109</td>
</tr>
<tr>
<td>10.4</td>
<td>Quadrant display of a device under test showing (a) unpowered radiance, (b) powered radiance, (c) emissivity, and (d) “true temperature”</td>
<td>111</td>
</tr>
<tr>
<td>10.5</td>
<td>Wire drawing machine capstan thermograms showing (a) proper cooling, and (b) improper cooling</td>
<td>111</td>
</tr>
<tr>
<td>10.6</td>
<td>Using the same imager with different filters to measure temperatures of the filaments (top thermogram) and the glass envelope (bottom thermogram)</td>
<td>113</td>
</tr>
<tr>
<td>10.7</td>
<td>Thermal image process control using a line scanner and set points</td>
<td>114</td>
</tr>
<tr>
<td>10.8</td>
<td>Full image process control using a line scanner and multiple zones: (a) before implementation of full image process control; (b) after implementation of full image process control</td>
<td>115</td>
</tr>
<tr>
<td>11.1</td>
<td>Thermogram of a vessel at sea at night in fog (8–12 µm)</td>
<td>119</td>
</tr>
<tr>
<td>11.2</td>
<td>Thermogram of an intruder at night (8–12 µm)</td>
<td>120</td>
</tr>
<tr>
<td>11.3</td>
<td>Hidden compartment in a vehicle</td>
<td>120</td>
</tr>
<tr>
<td>11.4</td>
<td>Driver’s thermal image compared to visible image</td>
<td>121</td>
</tr>
<tr>
<td>11.5</td>
<td>Thermogram of freeway traffic at night (8–12 µm)</td>
<td>122</td>
</tr>
<tr>
<td>11.6</td>
<td>(a) Visible, (b) thermal, and (c) fused images with smoke</td>
<td>122</td>
</tr>
<tr>
<td>11.7</td>
<td>View of a military helicopter from the ground</td>
<td>122</td>
</tr>
<tr>
<td>12.1</td>
<td>Sample breast thermograms of three patients: (a) normal, (b) fibrosystic changes, and (c) early stage malignant tumor</td>
<td>124</td>
</tr>
<tr>
<td>12.2</td>
<td>Confirmed inflammations at two different locations on a dog’s back</td>
<td>124</td>
</tr>
<tr>
<td>12.3</td>
<td>Thermographic results of SARS screening: (a) normal subject, and (b) febrile subject</td>
<td>125</td>
</tr>
<tr>
<td>A-1</td>
<td>Target and instrument background</td>
<td>156</td>
</tr>
</tbody>
</table>
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Temperature conversion chart</td>
<td>30</td>
</tr>
<tr>
<td>6.1</td>
<td>Industrial applications of thermal sensing and imaging instruments by industry</td>
<td>77</td>
</tr>
<tr>
<td>6.2</td>
<td>Industrial applications of thermal sensing and imaging instruments by discipline</td>
<td>78</td>
</tr>
<tr>
<td>7.1</td>
<td>Classification of electrical faults</td>
<td>84</td>
</tr>
<tr>
<td>7.2</td>
<td>Compensating for wind effects</td>
<td>85</td>
</tr>
</tbody>
</table>
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
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCMCIA</td>
<td>Personal Computer Memory Card International Association</td>
</tr>
<tr>
<td>PI</td>
<td>proportional plus integral</td>
</tr>
<tr>
<td>PID</td>
<td>proportional plus integral plus differential</td>
</tr>
<tr>
<td>QWIP</td>
<td>quantum well infrared photodetector</td>
</tr>
<tr>
<td>SRF</td>
<td>slit response function</td>
</tr>
<tr>
<td>SWIR</td>
<td>short-wave infrared region</td>
</tr>
<tr>
<td>TE</td>
<td>thermoelectric</td>
</tr>
<tr>
<td>TFOV</td>
<td>total field of view</td>
</tr>
<tr>
<td>TLV</td>
<td>thermal light valve</td>
</tr>
<tr>
<td>TRIR</td>
<td>time-resolved infrared radiometry</td>
</tr>
<tr>
<td>TSR</td>
<td>thermographic signal reconstruction</td>
</tr>
<tr>
<td>VDC</td>
<td>volts DC</td>
</tr>
</tbody>
</table>
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
4. Process Monitoring and Control
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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Honeywell Corp.
Linear Laboratories, Safetytek Corp.
Magnavox Electro-optical Systems
Meditherm
Mikron Infrared
Mine Safety Appliances Corp.
Quantum Focus Instruments
Raytek, Inc., a Fluke company
Raytheon Corp.
SI Termografia Infrareda
Thermal Wave Imaging, Inc.
Toledo Edison
Waterfall Solutions

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Boynton Beach, Florida
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