COMMON SENSE APPROACH TO THERMAL IMAGING

Gerald C. Holst

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COVER: Mid-wave infrared image of the Great Pyramid of Cheops and the Sphinx. Scene temperatures are represented by pseudo-colors. The sky is cold and appears black. The sun is overhead so that the top of the Sphinx and the ground behind the Sphinx are hot. They appear white. Intermediate temperatures are represented by yellows and reds (By courtesy of Stan Laband).

This book is dedicated to

Mom and Dad

They provide continual guidance

PREFACE

Objects are characterized by a variety of physical parameters such as size, shape, and weight. However, the most frequently measured physical property is temperature. Heat is a byproduct of all work whether it is from electrical, mechanical, or chemical activity. We generate, contain, and transfer heat to run our industries and make our everyday lives comfortable. Unexpected temperature variations may indicate design flaws, poor workmanship, or damaged components. A temperature variation can also be used to recognize an intruder, locate a buried object, or to identify geological events.

Thermal imaging systems are used by the military to detect, recognize, and identify enemy personnel, equipment, and buildings. Police patrol border crossings and use thermal imaging systems for search and rescue. The systems are particularly useful for evaluating the condition of power lines, transformers, circuit breakers, and motors. Simply put, they can be used to evaluate the "health" of any electrical or mechanical component.

Several texts that describe the applications of thermal imaging systems are:

Nondestructive Evaluation of Materials by Infrared Thermography, X.P.V. Maldague, Springer-Verlag, New York (1992).

Applications of Thermal Imaging, S. G. Burney, T. L. Williams, and C.H.N. Jones, Adam Hilger, Philadelphia, PA (1988).

Practical Applications on Infrared Thermal Sensing and Imaging Equipment, second edition, H. Kaplan, SPIE Press Vol. TT34, Bellingham WA (1999).

SPIE has assembled two compendiums:

Selected SPIE papers on Thermal Sensing and Imaging 1980-1999, SPIE CD-ROM, Volume 7, J. Snell and D. Burleigh, eds. (1999).

Selected Papers on Temperature Sensing: Optical Methods, R.D. Lucier, ed., SPIE Milestone Series Vol. MS 1164, Bellingham WA (1995).

The first compendium is a collection of papers from the proceedings of the SPIE conference *Thermosense*. Since this is an important contribution to the literature, Appendix C of this book contains the Table of Contents of the CD-ROM. The second contains reprints of articles that appeared in professional journals.

This book differs from those texts by clearly describing the phenomenology of heat transfer and providing numerous thermograms to support the concepts. It also covers a diverse set of applications. This book is divided into two parts. The first part (Chapters 1-9) provides the physics background that is necessary to interpret thermograms. The second part (Chapters 10-20) discusses various applications. Except for Chapter 19, *Nondestructive Testing*, minimal math is used in the second part. Heat transfer during nondestructive testing is a complex phenomenon and therefore requires more math. The researcher and scientist will read the first part in detail whereas the thermographer performing inspections will concentrate on the second part.

Heat transfer (Chapter 2), radiation theory (Chapter 3), and emissivity (Chapter 4) form the backbone of all thermal imaging system applications. The atmosphere (Chapter 5) may attenuate the received signal. This becomes an issue over long path lengths - typical of military applications. Camera design, performance parameters, and camera selection are contained in Chapters 6 through 8. It is can not be understated that each camera has specific design features and unique performance parameters. As a result, it is somewhat of a challenge to find a system that is *best* for a specific application. Interpretation of thermograms requires training (Chapter 9). This training must include the material provided in Chapters 2 through 5.

Part 2 begins with an introduction to applications (Chapter 10). Chapter 11 discusses the influence of the environment of target signatures. With this knowledge, it is possible to perform quantitative temperature measurements. For some tests, qualitative results are adequate. These include building envelope inspections (Chapter 13), roof inspections (Chapter 14), and the location of buried objects (Chapter 17). Electrical and mechanical inspections often require quantitative results (Chapters 15 and 16). Here, the temperature of a component is compared to a standard or guideline. If the temperature is too high, then the component must be repaired or replaced. Although surveillance refers to the observation of a person, this definition is extended to include the detection, recognition, and identification of both people and objects (Chapter 18). It includes search and rescue, endangered species monitoring, border patrol, law enforcement, and military applications. Nondestructive testing (Chapter 19) can locate disbonding, delamination, and corrosion. These are of prime concern of our aging commercial aircraft. Chapter 20 briefly discusses applications in six different industries. Chapter 21 lists the steps necessary for a successful test or inspection.

The physics is described by three equations. The first is the “easy” approach to describe the phenomenology. For example, the output of a detector is given by

$$V_{DETECTOR} = kR_D M$$

where R_D is the detector’s responsivity, M is the radiation from the target, and k is a constant. The effect of R_D and M on $V_{DETECTOR}$ is described and supported by numerous examples. Then the concept of wavelength, λ, is introduced with the second equation. The radiant intensity also depends upon the target’s temperature, T. The sum of all the outputs at the various wavelengths must be added together.

This is represented by an integral (third equation):

$$V_{CAMERA} = \int_{\lambda_1}^{\lambda_2} V_{DETECTOR}(\lambda)\, d\lambda .$$

Long-wave infrared (LWIR) and mid-wave infrared (MWIR) systems have different wavelength intervals [λ_1, λ_2]. The reader who is less interested in the math complexities will use the first equation. But he will fully understand the phenomenology. If detailed calculations are necessary, the reader will use the third equation. This last equation provides the guidance in selecting an appropriate camera for a specific application (i.e., MWIR or LWIR camera).

By using both simple and complex math, this book is intended for all that work with thermal imaging systems. This includes the researcher, system designer, test engineer, salesman, and end user. Since civilian and military applications are discussed, this book is useful to both communities.

The scientific community and many industries around the world use the metric system and it is used in this book. However, some industries in the U.S. and other countries still use English units. The conversion from miles per hour (mph) to meters per second (m/s) and degrees Fahrenheit (^{o}F) to degrees Celsius (^{o}C) are straightforward. While the reader can easily make the conversion, it takes time and it interrupts reading comprehension. Therefore, the English equivalent is always provided parenthetically.

I extend my deepest gratitude to all my coworkers and students who have contributed to the ideas in this book. They are too many to mention by name. I especially thank all those who read draft copies of the manuscript: Mary Lee Cassetta, consultant; Arnold Daniels, Optics-1; Dennis Hewins, Academy of Infrared Thermography; A. J. Holst, American Credit; Chris Johnston, IRcameras.com; Ron Newport, Academy of Infrared Thermography; Harold Orlando, Northrup Grumman; Jim Porter, Raytheon Systems; Dr. Austin Richards, Indigo; Elliot Rittenberg, EFR Associates; John Snell, Snell Infrared; and Gary Weil, EnTech Engineering. Although these reviewers provided valuable comments, the accuracy of the text is solely my responsibility. Douglas F. Marks provided the graphics and manuscript layout.

The thermograms were obtained from a number of sources. However, some images have been so widely distributed that the original owner is not known to many. If I missed a credit or gave credit to the wrong person, I apologize. Every attempt has been made to authenticate the owners. I hope that you find the title accurate: That this book **IS** the common sense approach to thermal imaging.

Gerald C. Holst *Winter Park, FL*

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