REMOTE SENSING AND IMAGE INTERPRETATION

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PREFACE

This book has been prepared primarily for use in introductory courses in remote sensing. Engineers, soil scientists, foresters, geologists, geographers, oceanographers, land planners, meteorologists, water resource managers, biologists—anyone involved in measuring, studying, and managing earth resources—should find it valuable both as a textbook and as a reference. It focuses on remote sensing systems and illustrates their utility in a diverse range of data gathering applications.

The book provides a broad, yet not superficial, introduction to the subject of remote sensing. No book can cover all aspects of the theory and practice of remote sensing and most textbooks on the subject are either narrowly focused, dealing with particular sensors or applications, or are multi-authored compendia. This book is a two-person effort aimed at *synthesizing* the subject of remote sensing so that the student might become equipped to understand and apply the appropriate aspects of remote sensing technology to his or her discipline.

We have made every attempt to be clear, concise, thorough, and objective. We have gone beyond the "black box" approach, yet we have written a book for upper division students studying earth resource management, not for electronics experts or theoretical mathematicians. All the "classical" elements of aerial photographic interpretation and photogrammetry are described, but we also introduce the concepts of interpreting images from nonphotographic sensors—both visually and through the application of digital image processing techniques.

After presenting the basic physical

principles on which remote sensing is based, the first half of this book concentrates on photographic remote sensing techniques. We treat the tools of the photographic trade (cameras, films, and so on), then provide a general introduction to the airphoto interpretation process. This introduction includes sample applications of airphoto interpretation in specific mapping tasks, such as land use/land cover mapping (including land information system design concepts), wetlands mapping, and geologic and soils mapping. We also discuss, in very general terms, the application of airphoto interpretation to the fields of agriculture, forestry, water resources, urban and regional planning, wildlife ecology, archeology, and environmental impact assessment. An entire chapter is devoted to terrain evaluation via airphoto interpretation.

The metric aspects of dealing with airphotos are covered in our discussion of photogrammetry, which includes a description of how to make reliable measurements from aerial photographs and consideration of how topographic mapping is accomplished through the use of stereoplotter instruments. We also discuss the preparation and characteristics of orthophotography, along with the process of planning a photographic mission.

Our treatment of photographic remote sensing procedures concludes with discussion of the radiometric characteristics of aerial photographs. This involves the details of how to radiometrically calibrate aerial photography and make image density measurements.

The second half of the book deals with the principles of acquiring and interpreting data collected by nonphotographic sensors. We describe thermal scanners, multispectral scanners, and radar systems. As with our discussion of photographic techniques, we illustrate how images produced from these systems are interpreted in various application areas. The general realm of digital image processing is described, with particular emphasis on the principles of spectral pattern recognition and image enhancement.

There is enough material in this book for it to be used in many different ways in many different course settings. These include courses in remote sensing, photo interpretation, and photogrammetry. Some courses may omit certain chapters and use the book in a one-semester or one-quarter course; the book may also be used in a two-course sequence. We have attempted to design the book with these two different potential uses in mind.

Where pictures were important in formulating the text, we used pictures. Where principle was more important than detail, we sacrificed detail. The International System of Units (SI) is used throughout the book. Numerical examples are given where appropriate. At the end of each chapter a selected bibliography appears that include works specifically cited plus other books and articles recommended for additional reading on various topics.

Although we have discussed remote sensing systems ranging from handheld 35 mm cameras to the Landsat series of satellites, we have limited the scope of this book to *electromagnetic* remote sensing of *earth resources*. Consequently, there is a multitude of remote sensing systems and application areas we do not treat. At the same time, remote sensing is such a dynamic field that some of what we present here may soon be outdated. Nonetheless, this book should enable the student to understand the business of stepping back—figuratively speaking—with image in hand and studying the broader perspective of our earth, its resources, and their environment.

The authors wish to express their sincere thanks to the many individuals who have contributed to this book. Specifically, we are grateful to Professor Roger M. Hoffer, of the Purdue University Laboratory for Applications of Remote Sensing, whose thorough review of the original draft of this entire manuscript and numerous suggestions were extremely valuable. Portions of the original manuscript were also reviewed by: Professor Robert H. Brock and Professor William M. Stiteler of the State University of New York College of Environmental Science and Forestry, Syracuse, New York; Professor James L. Clapp of the University of Maine, Orono, Maine; Professor David M. Mickelson, Professor Robert P. Madding, Professor Francis D. Hole, and Professor Frank L. Scarpace of the University of Wisconsin, Madison; Dr. Robert G. Reeves and Dr. James V. Taranik of the EROS Data Center, Sioux Falls, South Dakota; Dr. Alan S. Barnett, of Optronics International Inc., Chelmsford, Massachusetts; Mr. Norman L. Fritz of the Eastman Kodak Company, Rochester, New York; Professor Steven D. Johnson of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia; Dr. Kenneth R. Piech of Calspan Corporation, Buffalo, New York; Professor Floyd M. Henderson of the State University of New York, Albany, New York; Professor Anthony J. Lewis of Louisiana State University; Professor Dieter Steiner of the Geographisches Institut, Zurich, Switzerland; Mr. Alan W. Voss of the Tennessee Valley Authority, Chattanooga, Tennessee; Dr. Ronald W. Stingelin of HRB-Singer, Inc., State College, Pennsylvania; and Dr. Richard S. Williams, Jr., U.S. Geological Survey, Reston, Virginia.

The authors also wish to thank their many graduate and undergraduate students who made valuable contributions to this book. We are also grateful to the various individuals, instrument manufacturers, government agencies, and commercial firms who provided background materials and many of the illustrations used in this book. Almost every original line drawing and many of the photographic illustrations in this book were produced by Douglas E. Meisner and William L. Johnson—their contributions to all aspects of preparing this book have been invaluable. Their participation in the preparation of this book was supported by the State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

And finally, special recognition is due the authors' families, who provided three years of patient understanding and encouragement while this book was in preparation

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Color Plates Omitted

1 CONCEPTS AND FOUNDATIONS OF REMOTE SENSING

1.1 INTRODUCTION

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. As you read these words you are employing remote sensing. Your eyes are acting as sensors that respond to the light reflected from this page. The "data" your eyes acquire are impulses corresponding to the amount of light reflected from the dark and light areas on the page. These data are analyzed, or interpreted, in your mental computer to enable you to explain the dark areas on the page as a collection of letters forming words. Beyond this, you recognize that the words form sentences, and interpret the information that the sentences convey.

In many respects, remote sensing can be thought of as a reading process. Using various sensors we remotely collect *data* that may be analyzed to obtain *information* about the objects, areas, or phenomena being investigated. The remotely collected data can be of many forms, including variations in force distributions, acoustic wave distributions, or electromagnetic energy distributions. For example, a gravity meter acquires data on variations in the distribution of the force of gravity. Sonar, like a bat's navigation system, obtains data on variations in acoustic wave distributions. Our eyes acquire data on variations in electromagnetic energy distributions.

This book is about *electromagnetic* energy sensors that are currently being operated from airborne and spaceborne platforms to assist in inventorying, mapping, and monitoring earth resources. These sensors acquire data on the way various earth surface features emit and reflect electromagnetic energy and these data are analyzed to provide information about the resources under investigation.

Figure 1.1 schematically illustrates the generalized processes and elements involved in electromagnetic remote sensing of earth resources. The two basic processes involved are *data acquisition* and *data analysis*. The elements of the data acquisition process are: energy sources (*a*), propagation of energy through the atmosphere (*b*), energy interactions with earth surface features (*c*), airborne and/or spaceborne sensors (*d*), resulting in the generation of sensor data in pictorial and/or numerical form (*e*). In short, we use sensors to record variations in the way earth surface features reflect and emit electromagnetic energy. The data analysis process (*f*) involves examining the data using various viewing and interpretation devices to analyze pictorial data, and/or a computer to analyze numerical sensor data. Reference data about the resources being studied (such as soils maps, crop statistics, or field-check data) are used when and where available to assist in the data analysis. With the aid of the reference data, the analyst extracts information about the type, extent, location, and condition of the various resources over which the sensor data were collected. This information is then presented (*g*), generally in the form of maps, tables, and a written discussion or report. Typical information products are such things as land use maps and crop area statistics. Finally, the information is presented to users (*h*) who apply it to their decision-making process.

In the remainder of this chapter, we discuss the basic principles underlying the remote sensing process. We begin with the fundamentals of electromagnetic energy, then consider how the energy interacts with earth surface features. We also treat the role that reference data play in the data analysis procedure. These basics will permit us to conceptualize an "ideal" remote sensing system. With that as a framework, we consider the limitations encountered in "real" remote sensing systems. At the end of this discussion, the reader should have a grasp of the general concepts and foundations of remote sensing.

1.2 ENERGY SOURCES AND RADIATION PRINCIPLES

Visible light is only one of many forms of electromagnetic energy. Radio waves, heat, ultraviolet rays, and X-rays are other familiar forms. All this energy is inherently similar and radiates in accordance with basic wave theory. As shown in Figure 1.2, this theory describes electromagnetic energy as traveling in a harmonic, sinusoidal fashion at the "velocity of light," c. The

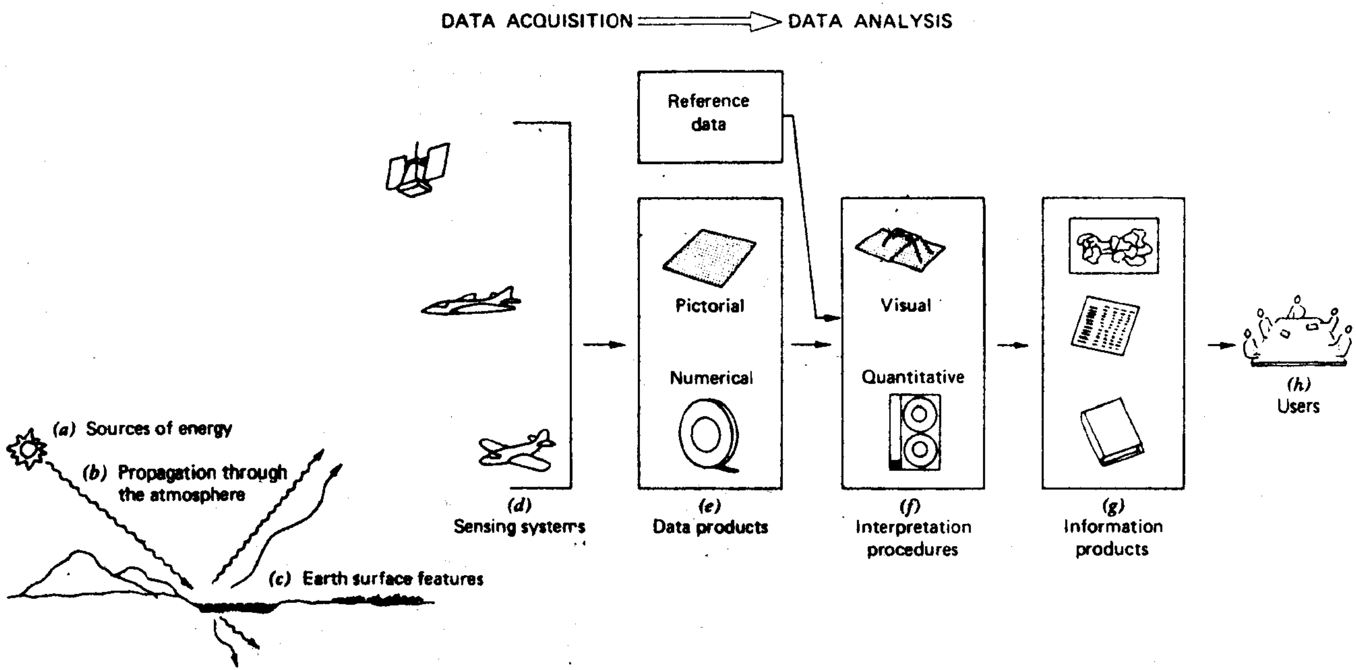

Figure 1.1 Electromagnetic remote sensing of earth resources.

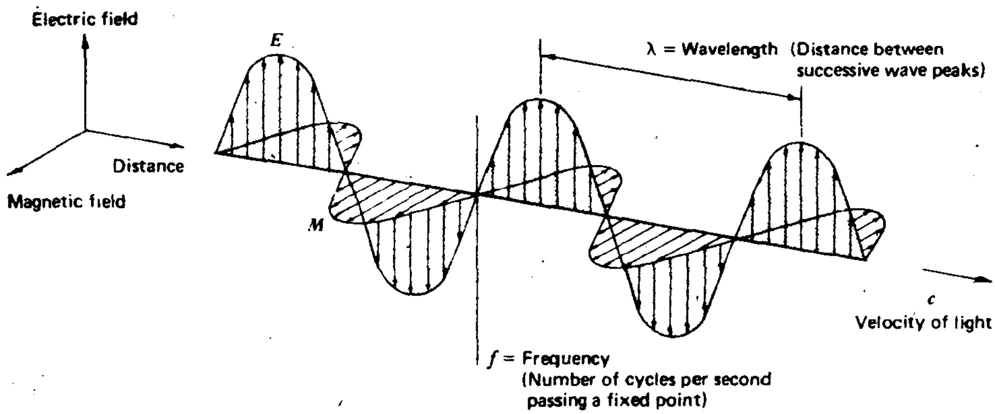

Figure 1.2 An electromagnetic wave. Components include a sinusoidal electric wave (*E*) and a similar magnetic wave (*M*) at right angles, both being perpendicular to the direction of propagation.

distance from one wave peak to the next is *wavelength* λ, and the number of peaks passing a fixed point in space per unit time is the wave *frequency* f.

From basic physics, waves obey the general equation

$$c = f\lambda \tag{1.1}$$

Since c is essentially a constant (3×10^8m/sec), frequency f and wavelength λ for any given wave are related inversely, and either term can be used to characterize a wave into a particular form. In remote sensing, it is most common to categorize electromagnetic waves by their wavelength location within the *electromagnetic spectrum* (Figure 1.3). The most prevalent unit used to measure wavelength along the spectrum is the *micrometer* (μm). A micrometer equals 1×10^{-6}m.

Although names are generally assigned to regions of the electromagnetic spectrum for convenience (such as ultraviolet and microwave), there is no clear-cut dividing line between one nominal spectral region and the next. Divisions of the spectrum have grown out of the various methods for sensing each type of radiation more so than from inherent differences in the energy characteristics of various wavelengths. Also, it should be noted that the portions of the electromagnetic spectrum used in remote sensing lie along a continuum characterized by magnitude changes of many powers of 10. Hence, the use of logarithmic plots to depict the electromagnetic spectrum is quite common. The "visible" portion of such a plot is an extremely small one, since the spectral sensitivity of the human eye extends only from about 0.4 μm to approximately 0.7 μm. The color "blue" is ascribed to the approximate range

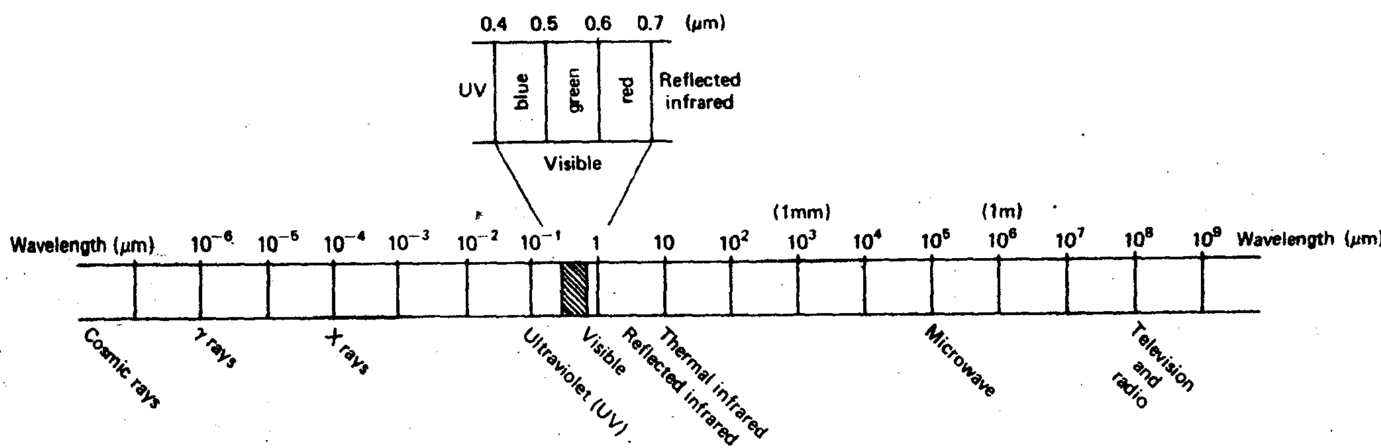

Figure 1.3 The electromagnetic spectrum.

of 0.4 to 0.5 μm, "green" to 0.5 to 0.6 μm, and "red" to 0.6 to 0.7 μm. *Ultraviolet* energy extends just to the short wavelength side of the visible spectral region. To the long wavelength side of the visible region are *reflected infrared (IR)* waves. To the long wavelength side of these waves is *thermal IR* energy. At much longer wavelengths (1 mm to 1 m) is the *microwave* portion of the spectrum.

Most common sensing systems operate in one or several of the visible, reflected IR, thermal IR, or microwave portions of the spectrum. Note that we make an important distinction between "reflected" IR and "thermal" IR energy. Thermal IR is directly related to the sensation of heat; reflected IR is not.

Although many characteristics of electromagnetic radiation are most easily described by wave theory, another theory offers useful insights into how electromagnetic energy interacts with matter. This theory—the particle theory—suggests that electromagnetic radiation is composed of many discrete units called *photons*, or *quanta*. The energy of a quantum is given as

$$E = hf \tag{1.2}$$

where
E = energy of a quantum, Joules (J)
h = Planck's constant, 6.626×10^{-34} J sec

We can relate the wave and quantum models of electromagnetic radiation behavior by solving Eq. 1.1 for f and substituting into Eq. 1.2 to obtain

$$E = \frac{hc}{\lambda} \tag{1.3}$$

Thus, we see that the energy of a quantum is inversely proportional to its wavelength. ***The longer the wavelength involved, the lower its energy content.*** This has important implications in remote sensing from the standpoint that naturally emitted long wavelength radiation, such as microwave emission from terrain features, is more difficult to sense than radiation of shorter wavelengths, such as emitted thermal IR energy. The low energy content of long wavelength radiation means that, in general, systems operating at long wavelengths must "view" large areas of the earth at any given time in order to obtain a detectable energy signal.

The sun is the most obvious source of electromagnetic radiation for remote sensing. However, *all* matter at temperatures above absolute zero (0°K, or −273°C) continuously emits electromagnetic radiation. Thus, terrestrial objects are also sources of radiation, though it is of considerably different mag-