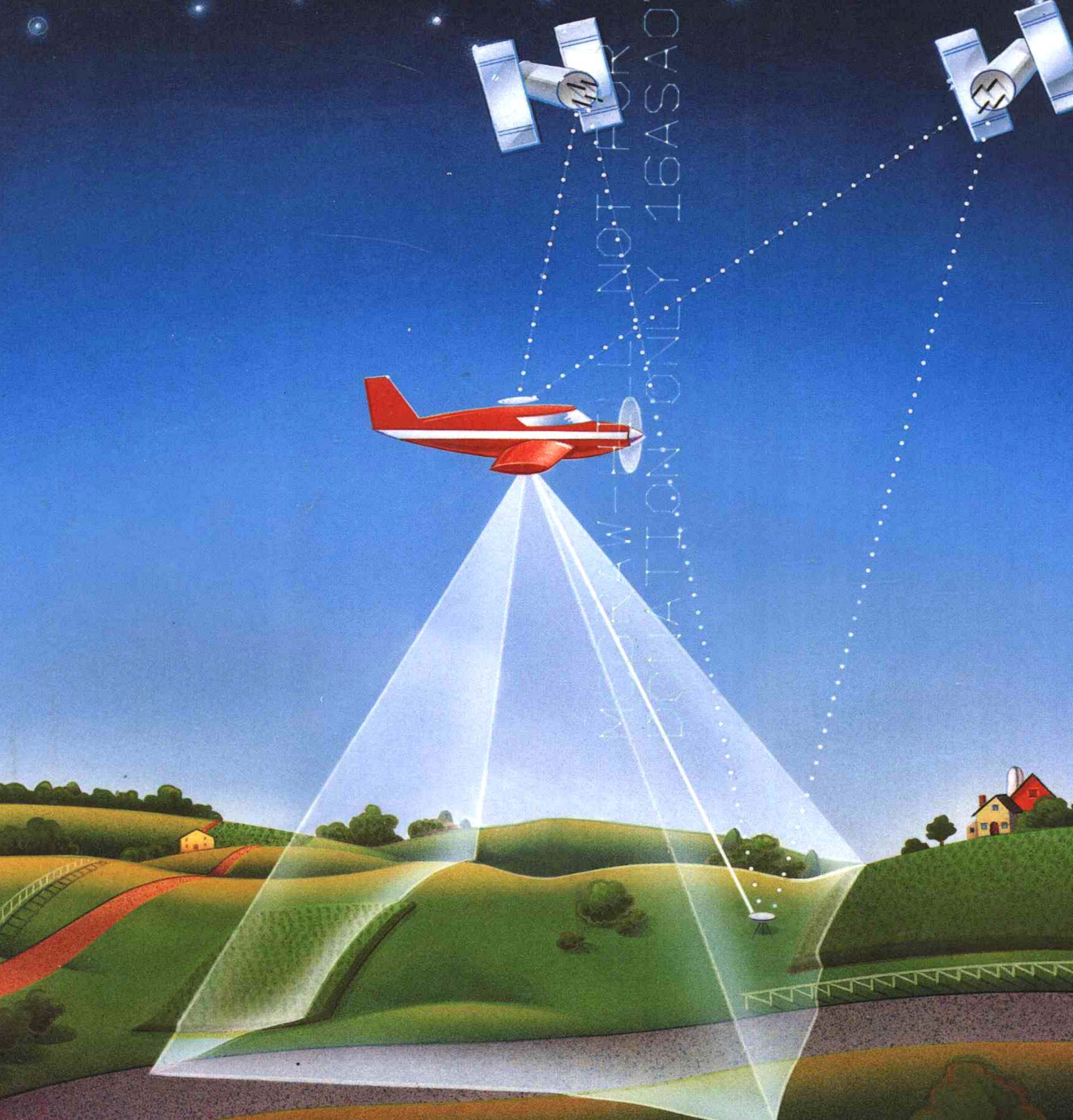
# Elements of Photogrammetry

## *with Applications in GIS*

3rd edition

Paul R. Wolf
Bon A. Dewitt



# ELEMENTS OF PHOTOGRAMMETRY

## With Applications in GIS

THIRD EDITION

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# PREFACE

Since the first edition of this book was published more than 25 years ago, many new technological developments have occurred in the areas of optics, electronics, computers, and satellite and space technology. Advancements in these and other areas have brought about significant changes in the instruments and procedures now used in the practice of photogrammetry. The changes have been particularly prevalent since the second edition of this book was published. Therefore, the foremost objective in preparing this third edition has been to update the book and incorporate these new developments. Another important objective, however, has been to include the many valuable improvements that have been suggested to the authors by professors, students, and practicing photogrammetrists who have used the first and second editions.

During the past decade, geographic information systems (GISs) have come of age, a development that has placed great new demands upon photogrammetry. GISs are computer-based systems that enable the storing, integrating, manipulating, analyzing, and displaying of virtually any type of spatially related information about our environment. These systems are now being used globally at all levels of government, and by businesses, private industry, and public utilities to assist in planning, design, maintenance, management, and decision making. Photogrammetry has arguably emerged as the most important discipline employed in the collection of spatially related information for use in GIS databases. A variety of photogrammetric products are generated for use in GISs; they include unrectified and rectified aerial photos, satellite images, maps of various types; digital orthophotos, digital elevation models, and other types of digital files containing topographic information. Because of the importance of photogrammetry in geographic information systems, a substantial amount of new GIS coverage is included in this edition. In fact, two new chapters have been added that are completely devoted to this topic: Chap. 20, Introduction to Geographic Information Systems, and Chap. 21, Photogrammetric Applications in GIS. Other coverage describing the role of photogrammetry in GISs is also given throughout the book. Even the title of this third edition has been expanded to identify the important relationship between photogrammetry and geographic information systems.

Coverage in this third edition has been updated to include many other major advances in modern photogrammetry. Substantial new material has been added, for example, on the subject of digital photogrammetry, also called *softcopy photogrammetry*. To support this area of study, digital images are discussed, digital cameras are described, and instruments and techniques for scanning hard-copy photos to create digital images are covered. Furthermore, a separate section on softcopy plotters, Part IV, has been added to Chap. 12, Stereoscopic Plotting Instruments. Finally, two completely new chapters on digital photogrammetry have been added; Chap. 14, Fundamental Principles of Digital Image Processing, and Chap. 15, Principles of Softcopy Photogrammetry.

Because photogrammetry plays such a vital role in generating spatially related information, it is imperative that students of this discipline have a firm grasp of the fundamentals of object space coordinate systems. To meet this goal, a new chapter has been added on this topic. It includes some elementary fundamentals of geodesy, describes various object space reference coordinate systems that are used in photogrammetry, and discusses map projections and datums. Also a new appendix has been added that describes and illustrates procedures for converting coordinates of points from one object space coordinate system to another.

Many other important additions have been made to this third edition. The chapter on control surveys for photogrammetry has been expanded to include new sections that describe the global positioning system (GPS) and the use of this equipment in performing ground control surveys. New coverage has also been added on procedures for incorporating a GPS receiver with an aerial camera during photographic missions. The subject of analytical photogrammetry has been significantly updated. This includes expanded coverage on the simultaneous bundle adjustment method, the addition of a new section on computing the bundle adjustment with airborne GPS control, and a new section that describes procedures for performing aerotriangulation by using satellite images. Other new material presented in this third edition includes discussions of instruments and computational techniques for producing digital orthophotos and digital elevation models, and a description of the new airborne laser mapping system.

The authors have endeavored to maintain the level and scope of coverage, and style of presentation, in this third edition consistent with those of the first two editions. The intent continues to be the production of a book that will be suitable for an introductory course in photogrammetry at the college level. This includes courses given at universities, junior colleges, technology colleges, schools of applied arts, and military schools. The book has also been written with the intent of making it suitable for self-study and reference. Thus it should be a valuable addition to the libraries of practicing photogrammetrists, geographic information specialists, cartographers, engineers, foresters, geologists, geographers, landscape architects, and others who use maps and photographs in their work.

As in the first two editions, the material in this third edition has been written using elementary terms as much as possible, and extensive use has been made of illustrations and diagrams. Many example problems have been included to clarify computational procedures, and the International System (*Système International,* or SI) units is used predominately throughout the book. In order that the book be suitable for students of varying levels of mathematical competence, the body of the text has been largely presented so that knowledge of only algebra, geometry, and trigonometry is necessary. More challenging mathematical developments have been placed in the appendixes, where they are available either for reference or for students having the necessary mathematics background.

The order of presentation has been arranged so that early chapters establish fundamental principles, while later chapters discuss more specialized aspects of photogrammetry. In general, each chapter is arranged so that the more important material is presented first, a feature that makes it convenient to cover only the first parts of certain chapters if course-time limitations will not allow covering the entire book. While the material has been kept as elementary as possible, the book's depth and breadth of coverage are sufficient to make it suitable for a second, more advanced course in photogrammetry. The coverage of the later chapters and the appendixes would be particularly useful in an advanced course.

A selected list of references is given at the end of each chapter, and from the materials cited, students can expand their knowledge on subjects of particular interest. Although only a limited number of key references are given, many also have extensive bibliographies which will lead students to numerous additional articles. Computer programs for solving selected photogrammetry problems are available to students and can be downloaded from the following Web site address: http://www.surv.ufl.edu/wolfdewitt. A solutions manual which contains answers to all after-chapter problems is also available to instructors from the publisher.

We wish to again acknowledge our sincere appreciation to the many individuals who contributed to the first and second editions of this book. And we gratefully acknowledge the people, agencies, and firms who contributed to this third edition. In particular, we express our thanks to Professors Paul Hopkins of the State University of New York at Syracuse, Robert Schultz of Oregon State University, and Steven Johnson of Purdue University for reviewing substantial portions of the manuscript; to Gary Johanning of Geodetic Services, Inc., who provided materials for Chap. 19 on close-range photogrammetry; to Professors Alan Vonderohe and Bernard Nieman of the University of Wisconsin–Madison for supplying materials used in the chapters on geographic information systems; to Diann Danielsen and Tim Confare of the Dane County Land Information Office, to Michelle Richardson of the Dane County Land Conservation Department, to Michael Bohn and Tom Simmons of the Wisconsin Department of Natural Resources, to Jay Arnold and Jeremy Conner of 3001, Inc., to Cyril Fernandez, Kay Brothers and Jason Mace of the Southern Nevada Water Authority, and to Tim Wolf (the author's son) of the Las Vegas Valley Water District, for materials used to illustrate applications of photogrammetry in geographic information systems; to Ken Worden and Steve Root of the Wisconsin Department of Transportation; to Fred Halfen of Ayres Associates; and to the numerous undergraduate and graduate students at both the University of Wisconsin–Madison and the University of Florida who provided suggestions, feedback, and assistance.

We also express our appreciation to the instrument manufacturers, government agencies, and private photogrammetric firms who supplied figures and other information for this book. We especially wish to thank Aerial Cartographics of America, Inc., and U.S. Imaging, Inc., for providing special aerial photography for the book.

Finally we wish to thank our wives, Lynn Wolf and Monica Dewitt, and our children for their patience, understanding, endurance, support, and love.

*Paul R. Wolf*
*Bon A. Dewitt*

# CONTENTS

# CHAPTER 1

# INTRODUCTION

## 1-1 DEFINITION OF PHOTOGRAMMETRY

*Photogrammetry* has been defined by the American Society for Photogrammetry and Remote Sensing as the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena. As implied by its name, the science originally consisted of analyzing photographs. Although photogrammetry has expanded to include analysis of other records, such as digital imagery, radiated acoustical energy patterns, laser ranging measurements, and magnetic phenomena, photographs are still the principal source of information. In this text *photographic* and *digital* photogrammetry are emphasized, but other sources of information are also discussed.

Included within the definition of photogrammetry are two distinct areas: (1) *metric* photogrammetry and (2) *interpretative* photogrammetry. Metric photogrammetry consists of making precise measurements from photos and other information sources to determine, in general, the relative locations of points. This enables finding distances, angles, areas, volumes, elevations, and sizes and shapes of objects. The most common applications of metric photogrammetry are the preparation of planimetric and topographic maps from photographs (see Secs. 13-2 through 13-6), and the production of digital orthophotos from scanned photography (see Sec. 13-7). The photographs are most often *aerial* (taken from an airborne vehicle), but *terrestrial* photos (taken from earth-based cameras) and satellite imagery are also used.

Interpretative photogrammetry deals principally in recognizing and identifying objects and judging their significance through careful and systematic analysis. It includes branches of *photographic interpretation* and *remote sensing*. Photographic interpretation includes the study of photographic images, while remote sensing includes not only the analysis of photography but also the use of data gathered from a wide variety of sensing instruments, including multispectral cameras, infrared sensors, thermal scanners, and side-looking airborne radar. Remote sensing instruments, which are often carried in vehicles as remote as orbiting satellites, are capable of providing quantitative as well as qualitative information about objects. At present, with our recognition of the importance of preserving our environment and natural resources, photographic interpretation and remote sensing are both being employed extensively as tools in management and planning.

Of the two distinct areas of photogrammetry, concentration in this book is on metric photogrammetry. Interpretative photogrammetry is discussed only briefly, and those students interested in further study in this area should consult the references cited at the end of this chapter.

## 1-2 HISTORY OF PHOTOGRAMMETRY

Developments leading to the present-day science of photogrammetry occurred long before the invention of photography. As early as 350 B.C. Aristotle had referred to the process of projecting images optically. In the early 18th century Dr. Brook Taylor published his treatise on linear perspective, and soon afterward, J. H. Lambert suggested that the principles of perspective could be used in preparing maps.

The actual practice of photogrammetry could not occur, of course, until a practical photographic process was developed. This occurred in 1839, when Louis Daguerre of Paris announced his direct photographic process. In his process the exposure was made on metal plates that had been light-sensitized with a coating of silver iodide. This is essentially the photographic process in use today.

A year after Daguerre's invention, Francois Arago, a geodesist with the French Academy of Science, demonstrated the use of photographs in topographic surveying. The first actual experiments in using photogrammetry for topographic mapping occurred in 1849 under the direction of Colonel Aimé Laussedat of the French Army Corps of Engineers. In Colonel Laussedat's experiments kites and balloons were used for taking aerial photographs. Due to difficulties encountered in obtaining aerial photographs, he curtailed this area of research and concentrated his efforts on mapping with terrestrial photographs. In 1859 Colonel Laussedat presented an accounting of his successes in mapping using photographs. His pioneering work and dedication to this subject earned him the title "father of photogrammetry."

Topographic mapping using photogrammetry was introduced to North America in 1886 by Captain Eduard Deville, the Surveyor General of Canada. He found Laussedat's principles extremely convenient for mapping the rugged mountains of western Canada. The U.S. Coast and Geodetic Survey (now the National Geodetic Survey) adopted photogrammetry in 1894 for mapping along the border between Canada and the Alaska Territory.

Meanwhile new developments in instrumentation, including improvements in cameras and films, continued to nurture the growth of photogrammetry. In 1861 a three-color photographic process was developed, and roll film was perfected in 1891. In 1909 Dr. Carl Pulfrich of Germany began to experiment with overlapping pairs of photographs. His work formed much of the foundation for the development of many instrumental photogrammetric mapping techniques in use today.

The invention of the airplane by the Wright brothers in 1902 provided the great impetus for the emergence of modern aerial photogrammetry. Until that time, almost all photogrammetric work was, for the lack of a practical means of obtaining aerial photos, limited to terrestrial photography. The airplane was first used in 1913 for obtaining photographs for mapping purposes. Aerial photos were used extensively during World War I, primarily in reconnaissance. In the period between World War I and World War II, aerial photogrammetry for topographic mapping progressed to the point of mass production of maps. Within this period many private firms and government agencies in North America and in Europe became engaged in photogrammetric work. During World War II, photogrammetric techniques were used extensively to meet the great new demand for maps. Air photo interpretation was also employed more widely than ever before in reconnaissance and intelligence. Out of this war-accelerated mapping program came many new developments in instruments and techniques.

Advancements in instrumentation and techniques in photogrammetry have continued at a rapid pace during the past 50 years. The many advancements are too numerous to itemize here, but collectively they have enabled photogrammetry to become the most accurate and efficient method available for compiling maps and generating topographic information. The improvements have affected all aspects of the science, and they incorporate many new developments such as those in optics, electronics, computers and satellite technology. While this text does include some historical background, its major thrust is to discuss and describe the current state of the art in photogrammetric instruments and techniques.

## 1-3 TYPES OF PHOTOGRAPHS

Two fundamental classifications of photography used in the science of photogrammetry are *terrestrial* and *aerial*. Terrestrial photographs (see Chap. 19) are taken with ground-based cameras, the position and orientation of which are often measured directly at the time of exposure. A great variety of cameras are used for taking terrestrial photographs, and these may include anything from simple hobby cameras, which are handheld, to precise specially designed cameras mounted on tripods. A *phototheodolite,* as shown in Fig. 1-1, is a combination camera and theodolite mounted on a tripod used for taking terrestrial photographs. The theodolite, a surveying instrument which is used to measure angles, facilitates aligning the camera in a desired or known azimuth and measuring its position and elevation. Figure 1-2 shows a terrestrial photograph taken with a camera of the type shown in Fig. 1-1.

Another special type of terrestrial camera, which was employed for important work in the past, is the *ballistic camera,* shown in Fig. 1-3. These large cameras were mounted at selected ground stations and used to obtain photographs of orbiting artificial satellites against a star background. The photographs were analyzed to calculate satellite trajectories; the size, shape, and gravity of the earth; and the precise positions of the camera stations. This procedure utilized precisely known camera constants, together with the

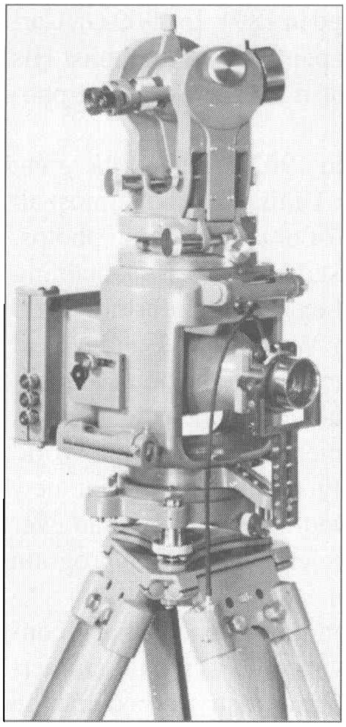

**FIGURE 1-1**
Phototheodolite used for taking terrestrial photographs. (*Courtesy LH Systems, LLC.*)

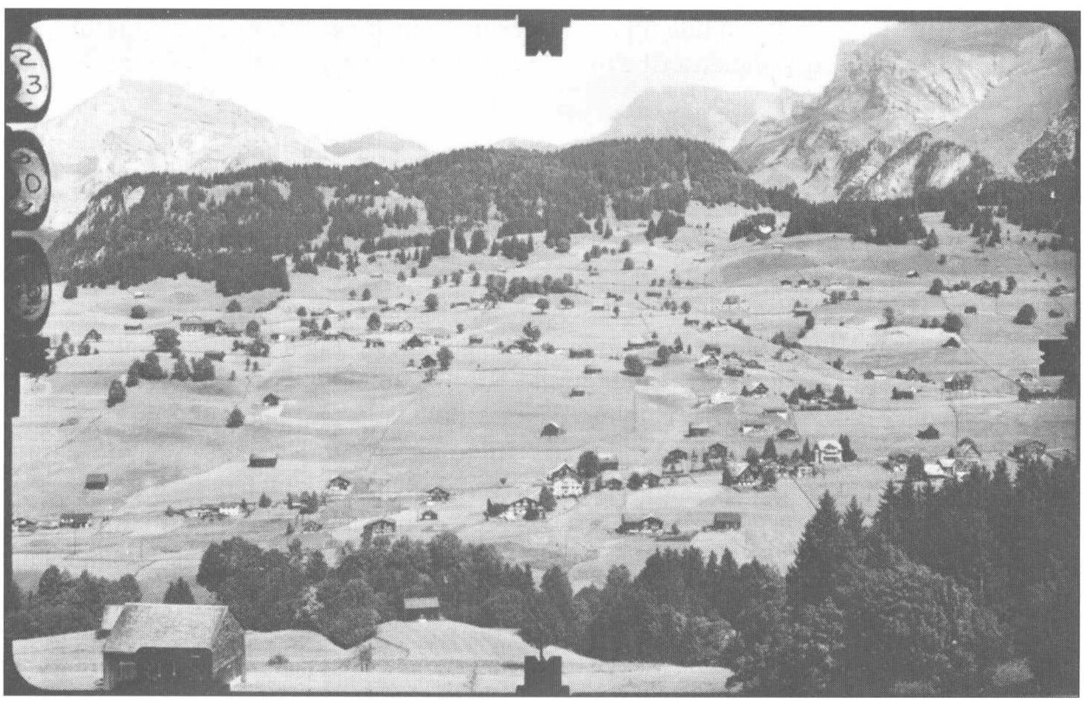

**FIGURE 1-2**
Terrestrial photograph. (*Courtesy LH Systems, LLC.*)