BUILDING EARTH OBSERVATION CAMERAS

GEORGE JOSEPH

CRC Press
Taylor & Francis Group

BUILDING EARTH OBSERVATION CAMERAS

GEORGE JOSEPH

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20141202

International Standard Book Number-13: 978-1-4665-6647-7 (Hardback)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

BUILDING EARTH OBSERVATION CAMERAS

Dedicated to

all my colleagues in SAC

and

other centers of ISRO

who contributed to build world-class

Earth observation cameras

Preface

Humankind has always marveled at viewing the Earth from great heights, because such perspectives provide a broader, holistic view of the neighborhood and the Earth's surface. Founded on this basic human trait, the ability to image any part of the globe from space and obtain a seamless perspective of the Earth's objects has become an important modern-day technological achievement. Today, there are many satellites that orbit the Earth (or, for that matter, are even in outer space) and provide images of the Earth using advanced imaging technology, bringing far-reaching impacts to humanity. Even though the use of imagery from space was initially for reconnaissance and military purposes, soon scientists recognized the potential of the images for many civilian and public-good applications and also for scientific understanding of the Earth as a total system, and a new discipline called *remote sensing* has emerged. Remote sensing has now paved the way for a large number of societal, commercial, and research applications in almost every nation of the world.

An important component of any remote sensing activity is the *imaging system*—the *eye in the sky*—that is not just a technological marvel in space but is a system of excellent engineering, based on sound physical principles. This then is the subject matter of this book—looking at imaging system technology and providing insights into different aspects of building an imaging system for a space platform. In principle, any part of the electromagnetic radiation within the *atmospheric window* can be the basis of remote sensing; the present book specifically deals with electro-optical sensors that operate in the optical–infrared region. Design, development, and characterization of such an imaging system and finally qualifying it for operations in space require intense knowledge in various disciplines of engineering and science. I believe that an overview of the total system is essential for any imaging system project manager. Such a broad understanding, generally, is difficult to find in one source textbook—though information is available in various specialized books, journals, and so on. I have tried to bridge this gap through this book.

I have written this book with manifold purposes. First, the book should be able to help practicing imaging system project managers and scholars and researchers of electro-optical sensor systems obtain fundamental information and a broad overview of various entities of imaging systems—thus, it should help them to look deeper into the systems that they are developing. Second, the application scientists who use satellite imagery should also find the book very helpful in understanding various technical aspects and the terminology used in defining the performance of the image system so that they can choose the most appropriate dataset for meeting their needs. Third, I foresee that this book will also serve as a guideline to the new entrants to this field to understand the concepts and challenges of building space-based Earth observation systems.

Writing this book has been a personal challenge for me. From my deep association with the development of electro-optical sensors, I find the subject to be so vast that each subsystem of an Earth observation camera deserves to be a book by itself—the challenge before me has been to *cover everything possible but keep it minimalistic*. Another challenge I foresaw was that because of the multidisciplinary nature of the imaging systems, the reader community would be quite varied across science and engineering disciplines. Thus, maintaining the structure of the book and presenting the content in a manner that can be appreciated by a range of readers has been always at the back of my mind. Therefore, I decided on three things: (1) the book must serve as much as possible as a single source of all technical aspects of imaging systems, (2) there should be broad coverage and so minimalistic depth, and (3) it should be interesting for the wide-ranging reader community. Of course, I give a long list of references at the end of each chapter—if anyone wants to deep dive, then that too would be possible.

In the opening chapter, the book traces the historical development of imaging systems and reviews the evolution of Earth observation systems in the world and the trends in the technology and end utilization. The second chapter provides the basic concepts and fundamental principles of image formation and the physical laws and principles. The next seven chapters cover various aspects of design, system trade-offs, realization, and characterization of various types of imaging systems—specific examples from Indian Remote Sensing (IRS) Satellite systems illustrate the design and development issues. To maintain continuity and facilitate nonspecialist in following the content easily, I have consciously repeated some definitions and explanations in later chapters though they are also explained earlier. There are a number of Earth observation systems—past and present. It is not possible to cover all of them. However, I have made a concerted effort to cover representative imaging systems from other agencies so that one can get an understanding and appreciate various engineering challenges that have been addressed in different manners. The last chapter gives a broad framework of the tasks involved in qualifying a payload for space use. I must make it abundantly clear that any references that I make to the Indian space program and the IRS are my personal views and have no endorsement of the Indian Space Research Organisation (ISRO) as an organization.

I am grateful to Dr. K. Radhakrishnan, the present chairman of ISRO, for giving me an honorary position in ISRO, without which I could not have accomplished this task. I am thankful to Dr. R. R. Navalgund and Prof. A. S. Kiran Kumar, the past and present directors of Space Applications Centre (SAC) who extended to me the necessary facilities in the course of preparation for the book. Many of my colleagues at ISRO/Department of Space (DOS) helped me in different manner—by giving valuable input,

generating tables and figures, critically going through the manuscript, and so on. There are so many of these wonderful colleagues that have helped me, but it is practically impossible to mention each of them by name. I am deeply indebted to all of them. My special thanks to A. V. Rajesh for generating many of the line drawings and the contributing to the cover page design and for the final formatting of the text.

My wife, Mercy, who, because of my professional involvement and pursuits has made many sacrifices over the years, deserves special thanks for her constant support and encouragement, without which the book would not have been finished. Our grandchildren—Nishita, Reshawn, and Riana—are always a source of inspiration to take up new challenges.

George Joseph

Author

Dr. George Joseph started his research career in 1962 at the Tata Institute of Fundamental Research (TIFR), Mumbai, where he was involved in the study of cosmic rays. For his pioneering work at TIFR on detection of emission of neutrons from the sun, he was awarded a PhD in 1971. In 1973, he was invited to join the Space Applications Centre (SAC), one of the major centers of the Indian Space Research Organization (ISRO), primarily for developing Earth observation systems. Under his leadership, a variety of Earth observation cameras were developed for the Indian Remote Sensing (IRS) Satellite and the Indian National Satellite (INSAT). Apart from being the guiding force for the development of Earth observation remote sensors developed by ISRO, Dr. Joseph has made substantial contributions toward the realization of various other remote-sensing-related activities. He served SAC in various capacities including as its director from 1994 to 1998.

Dr. Joseph has served in a number of national and international committees/organizations including president of Technical Commission–1 of the International Society for Photogrammetry and Remote Sensing (ISPRS) during 1996–2000. During 2006–2009, he was the director of the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTE-AP), affiliated to the United Nations. He is a fellow of a number of national academies such as the Indian Academy of Sciences; the National Academy of Sciences, India; and the Indian National Academy of Engineering. In recognition of his outstanding contributions to electro-optical sensor development and for his distinguished achievements in furthering remote sensing utilization in the country, the Government of India honored him in 1999 with a civilian award—the Padma Bhushan.

Contents

1

Introduction

From the humble beginnings of an invention of a pinhole camera around 1000 AD to highly sophisticated data gathering from space, the history of imaging has been a captivating series of technological advances and their applications. The most ancient pinhole camera, also known as the camera obscura, could just project an image of a scene outside, upside-down, onto a viewing surface. It was only around 1816 that Nicéphore Niépce became the first man to capture a camera image on a paper medium coated with silver chloride, which darkened where it was exposed to light. Shortly after, George Eastman created an epoch by making commercial cameras that could be used by nonspecialists, and the first Kodak camera entered the market in 1888 preloaded with enough film for 100 exposures.

Early humans used to climb up high mountains or treetops to get a better view of their surroundings to identify greener pastures or the threat of approaching hostile situations. In other words, a synoptic view was important for their survival. It is known that by 1858 humans could capture an aerial image, when Gaspard-Félix Tournachon (also known as Félix Nadar) took the first known aerial photograph by placing a camera on a balloon. Other methods to take aerial photographs included the use of kites and pigeons attached with cameras. Homing pigeons were used extensively during World War I. Also, aircraft platforms became indispensable means for reconnaissance during the world wars.

It was indeed the war needs that gave the maximum impetus for advancements in camera and photographic film. During world wars, obtaining intelligence about the enemy and their activities was one of the key needs for each warring side. The development of films capable of recording images in near infrared (NIR) was a boon to detect camouflaged objects. A green paint or even cut tree branches give different responses compared to a living tree canopy when imaged in NIR. Even after the end of World War II, during the ensuing Cold War, reconnaissance of others' territory was found essential. According to the international laws that were in force after World War II, each country had sovereign rights over its airspace—the portion of the atmosphere above its territory and up to a height that any aircraft could fly. Thus, any violation of air space entitles the affected country the right of self-defense and accordingly the right even to shoot down the intruders. A new dimension for reconnaissance began with the launch of Sputnik in 1957, which marked the beginning of space age, which soon granted the world nations a legal regime for activities in the space environment, which was declared as a province of all mankind and hence imaging on any territory from space was no bar. In the beginning, indeed, imaging of Earth from space was mostly used for snooping into others' territory!

The initial operational photoreconnaissance satellites of the United States, called CORONA, had photographic cameras, and after the mission the exposed film was ejected from the satellite and collected in midair for processing and exploitation. The camera system was nicknamed KH (keyhole). Beginning in 1960, several Corona systems were launched with cameras developed by Itek using Eastman Kodak film; early flights had spatial resolution in the rage of 10–12 m in early flights, and by 1972, the resolution improved to about 2–3 m. Soon after the first U.S. Corona mission, the Soviets also built successful photoreconnaissance satellites (Zenit). These photographic systems are broadly similar to the KH cameras. As technology advanced, KH became digital. The KH-11, also named CRYSTAL, launched in 1976 and was the first American spy satellite to use electro-optical digital imaging, using an 800 by 800 pixel charge-coupled device (CCD) array for imaging; hence it had a real-time observation capability. The 2.4 m diameter telescope of KH-11 could provide a theoretical ground resolution of about 15 cm, though the actual realized spatial resolution from orbit will be much poorer due to atmospheric and other effects. Because of the high secrecy involved, the technical details and capabilities of these satellites are not available in the public domain. The latest reconnaissance system, KH-12 (improved CRYSTAL), operates in the visible, NIR, and thermal infrared (TIR) regions of the electromagnetic (EM) spectrum. These sensors probably have low-light-level CCD image intensifiers, which can provide nighttime images. Thus, during the early years of imaging from space, military applications were responsible for most of the advances.

Scientists soon realized the potential of space imagery for varied civilian applications in fields such as geology, forestry, agriculture, cartography, and so on. After the world wars, the scientists pursued more vigorously the use of space imagery for the public good. A new term, "remote sensing," was added to the technical lexicon.

1.1 Remote Sensing

The term remote sensing literally means making observations about an object, where the sensor used is not in physical contact with the object under consideration. This is in contrast to in-situ measurement, for example measuring the body temperature using doctor's thermometer. Though any observation from a distance can be termed remote sensing, United Nations Resolution (41/65) dealing with "The Principles Relating to Remote Sensing of the Earth from Outer Space" adopted on December 3, 1986 defines remote sensing as follows: