Cambridge University Press
978-0-521-51611-2 - Image Registration for Remote Sensing
Edited by Jacqueline Le Moigne, Nathan S. Netanyahu and Roger D. Eastman
Excerpt
More information

Part I

The Importance of Image Registration for Remote Sensing

Cambridge University Press
978-0-521-51611-2 - Image Registration for Remote Sensing
Edited by Jacqueline Le Moigne, Nathan S. Netanyahu and Roger D. Eastman
Excerpt
More information

1

Introduction

JACQUELINE LE MOIGNE, NATHAN S. NETANYAHU, AND ROGER D. EASTMAN

Despite the importance of *image registration* to data integration and fusion in many fields, there are only a few books dedicated to the topic. None of the current, available books treats exclusively image registration of Earth (or space) satellite imagery. This is the first book dedicated fully to this discipline. The book surveys and presents various algorithmic approaches and applications of image registration in remote sensing. Although there are numerous approaches to the problem of registration, no single and clear solution stands out as a standard in the field of remote sensing, and the problem remains open for new, innovative approaches, as well as careful, systematic integration of existing methods. This book is intended to bring together a number of image registration approaches for study and comparison, so remote sensing scientists can review existing methods for application to their problems, and researchers in image registration can review remote sensing applications to understand how to improve their algorithms. The book contains invited contributions by many of the best researchers in the field, including contributions relating the experiences of several Earth science research teams working with operational software on imagery from major Earth satellite systems. Such systems include the Advanced Very High Resolution Radiometer (AVHRR), Landsat, MODerate resolution Imaging Spectrometer (MODIS), Satellite Pour l'Observation de la Terre (SPOT), VEGETATION, Multi-angle Imaging SpectroRadiometer (MISR), METEOSAT, and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS).

We have aimed this collection of contributions at researchers and professionals in academics, government and industry whose work serves the remote sensing community. The material in this book is appropriate for a mixed audience of image processing researchers spanning the fields of computer vision, robotic vision, pattern recognition, and machine vision, as well as space-based scientists working in the fields of Earth remote sensing, planetary studies, and deep space research. This audience represents many active research projects for which the collaboration between image processing researchers and Earth scientists is essential, as the former try to solve the problems posed by the latter. A common language is not only appropriate but also needed. Our intent is to ensure that the material is accessible to both audiences. We have strived to provide a broad overview of the field, ranging from theoretical advanced algorithms to applications, while maintaining rigor by including basic definitions and equations.

In the Introduction we focus on the basic essence of image registration and the main rationale for its pursuit in the domain of remote sensing. The individual contributions in the rest of the book cover extensively various ways in which image registration is carried out. Specifically, we will describe applications for which accurate and reliable image registration is essential, and briefly review their corresponding challenges. We will then define remote sensing, describe how remote sensing data are acquired, and consider characteristics of these data and their sources. Finally, we will summarize the overall contents of the book, and provide definitions of selected general terms used throughout the chapters.

1.1 A need for accurate image registration

Earth science studies often deal with issues such as predicting crop yield, evaluating climate change over multiple timescales, locating arable land and water sources, monitoring pollution, and understanding the impact of human activity on major Earth ecosystems. To address such issues, Earth scientists use the global and repetitive measurements provided by a wide variety of satellite remote sensing systems. Many of these satellites have been launched (e.g., the Earth Observing System (EOS) AM and PM platforms), while the launch of others is being planned (e.g., the Landsat Data Continuity Mission (LDCM)). All these systems support multiple-time or simultaneous observations of the same Earth features by different sensors. Viewing large areas of the Earth at very high altitudes by spaceborne, remote sensing systems provide global measurements that would not be available using ground or even airborne sensors, although these global measurements often need to be complemented by local or regional measurements to complete a more thorough investigation of the phenomena being observed.

Image registration for the integration of digital data from such disparate satellite, airborne, and ground sources has become critical for several reasons. For example, image registration plays an essential role in spatial and radiometric calibration of multitemporal measurements for obtaining large, integrated datasets for the long-term tracking of various phenomena. Also, change detection over time or scale is only possible if multisensor and multitemporal data are accurately calibrated through registration. Previous studies by Townshend *et al.* (1992) and Dai and Khorram (1998) showed that even a small error in registration might have a large impact on the accuracy of global change measurements. For example, when looking at simulated data of MODIS at 250-m spatial resolution, a misregistration error of one pixel can produce a 50% error in the computation of the Normalized Difference Vegetation Index (NDVI). Another reason for integrating multiple observations is the resulting capability of extrapolating data throughout several scales, as researchers may be interested in phenomena that interact at multiple scales, whether spatial, spectral, or temporal. Generally, changes caused by human activity occur at a much faster rate and affect much larger areas. For all these applications, very accurate registration, that is, *exact pixel-to-pixel matching of two different images or matching of one image to a map*, is one of the first requirements for making such data integration possible.

More generally, image registration for remote sensing can be classified as follows:

(1) *Multimodal registration*, which enables the integration of complementary information from different sensors. This suits, for example, land cover applications, such as agriculture and crop forecasting, water urban planning, rangeland monitoring, mineral and oil exploration, cartography, flood monitoring, disease control, real-estate tax monitoring, and detection of illegal crops. In many of these applications, the combination of remote sensing data and Geographic Information Systems (GISs), see, for example, Cary (1994), and Ehlers (1995), shows great promise in helping the decision-making process.
(2) *Temporal registration*, which can be used for change detection and Earth resource surveying, including monitoring of agricultural, geological, and land cover features extracted from data obtained from one or several sensors over a period of time. Cloud removal is another application of temporal registration, when observations over several days can be fused to create cloud-free data.
(3) *Viewpoint registration*, which integrates information from one moving platform or multiple platforms navigating together into three-dimensional models. Landmark navigation, formation flying and planet exploration are examples of applications that benefit from such registration.
(4) *Template registration*, which looks for the correspondence between new sensed data and a previously developed model or dataset. This is useful for content-based or object searching and map updating.

Scientific visualization and virtual reality, which create seamless mosaics of multiple sensor data, are other examples of applications which are based on various types of registration, in particular, multimodal, temporal, and viewpoint registration.

1.2 What is image registration?

As a general definition, image registration is the process of aligning two or more images, or one or more images with another data source, for example, a map containing vector data. An image is an array of single measurements, and alignment is provided by a mathematical transformation between geometric locations in two image arrays. To be mutually registered, two images should contain overlapping views of the same ground features. In the basic case, one image may need to be translated, or translated and rotated, to align it with the other. The problem of image-to-image registration is illustrated in Fig. 1.1, which shows a reference image, extracted from an IKONOS scene over Washington, DC, with a corresponding translated and rotated image. In later chapters we will consider complex transformations, beyond translation and rotation, for alignment of the images.

Image registration involves locating and matching similar regions in the two images to be registered. In manual registration, a human carries out these tasks visually using interactive software. In automatic registration, on the other hand, autonomous algorithms perform these tasks. In remote sensing, automated procedures do not always offer the needed reliability and accuracy, so manual registration is frequently used. The user extracts from both images distinctive locations, which are typically called *control points* (CPs), tie-points, or reference points. First, the CPs in both images (or datasets) are interactively matched pairwise to achieve correspondence. Then, corresponding CPs are used to compute the parameters of a geometric transformation in question. Most available commercial systems follow this registration approach. Manual CP selection represents, however, a repetitive, laborious, and time-intensive task that becomes prohibitive for large amounts of data. Also, since the interactive choice of control points in satellite images is sometimes difficult to begin with, and since often too few points, inaccurate points, or ill-distributed points might be chosen, manual registration could lead to large registration errors. The main goal of image registration research, in general, is to improve the accuracy, robustness, and efficiency of fully automatic, algorithmic approaches to the problem. Specifically, the primary objective of this book is to review and describe the main research avenues and several important applications of automatic image registration in remote sensing.

Usually, automatic image registration algorithms include three main steps (Brown, 1992):

(1) Extraction of distinct regions, or *features*, to be matched.
(2) *Matching* of the features by searching for a transformation that best aligns them.
(3) *Resampling* of one image to construct a new image in the coordinate system of the other, based on the computed transformation.

Automatic approaches differ in the way they solve each step. One algorithm may extract simple features, but use a complex matching strategy, while another may use rather complex features, but then employ a relative simple matching strategy. Chapter 3 provides a survey of many current automatic image registration methods,

CAMBRIDGE

Cambridge University Press
978-0-521-51611-2 - Image Registration for Remote Sensing
Edited by Jacqueline Le Moigne, Nathan S. Netanyahu and Roger D. Eastman
Excerpt
More information

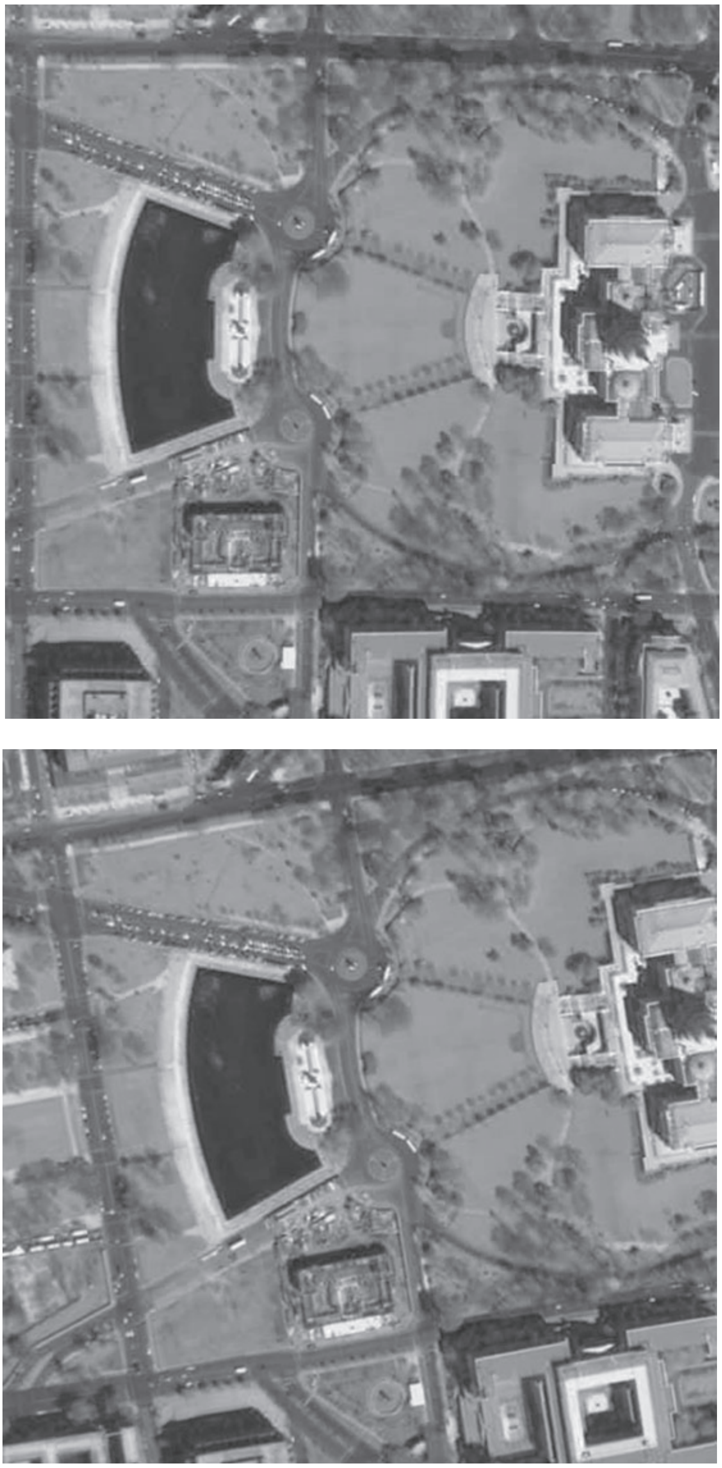

Figure 1.1. A reference image and its transformed image, extracted from an IKONOS scene acquired over Washington, DC. See color plates section. (IKONOS satellite imagery courtesy of GeoEye. Copyright 2009. All rights reserved.)

focusing mainly on their feature extraction and matching steps. Additional chapters discuss particular algorithmic approaches, and several other chapters describe ground control systems successfully implemented for satellite systems.

This book mainly deals with feature extraction and matching. While feature extraction and matching must be integrated, resampling is performed post-matching and can be handled relatively independently. For some applications, this step is replaced by an indexing of the incoming data into an absolute reference system, for example, a (latitude, longitude) reference system for Earth satellite data. Doing so preserves the original data values, which can be important for scientific applications. When several data sources are integrated, the resampling step can be replaced or supplemented by the fusion process. Finally, an automatic method may have two resampling stages. A temporary stage is used during matching to increase the similarity of the two images, but its results are discarded while a second, more accurate phase is used for the production of the final image product.

More generally, for all the applications described in Section 1.1, the main requirements from an image georegistration system are accuracy, consistency (i.e., robustness), speed, and a high level of autonomy that will facilitate the processing of large amounts of data in real time. With the goal of developing such a system, the purpose of this book is to examine the specific issues related to image registration in the particular domain of remote sensing, and to describe the methods that have been proposed to solve these issues. Before describing these methods, we first look at how remote sensing data are being acquired.

1.3 Remote sensing fundamentals

Remote sensing can be defined as the process by which information about an object or phenomenon is acquired from a remote location (e.g., an aircraft or a satellite). More specifically, satellite/sensing imaging refers to the use of sensors located on spaceborne platforms to capture electromagnetic energy that is reflected or emitted from a planetary surface such as the Earth. The Sun, like all terrestrial objects, is a source of energy. The sensors are either *passive* or *active*, that is, all energy which is observed by passive satellite sensors originates either from the Sun or from planetary surface features, while active sensors, such as radar systems, utilize their own source of energy to capture or image specific targets.

All objects give off radiation at all wavelengths, but the emitted energy varies with the wavelength and with the temperature of the object. A *blackbody* is an ideal object that absorbs and reemits all incident energy, without reflecting any. According to Stefan-Boltzman's and Wien's displacement laws (Lillesand and Kiefer, 1987; Campbell, 1996), a *dominant wavelength*, defined as the wavelength at which the total radiant exitance is maximum, can be computed for all blackbodies.

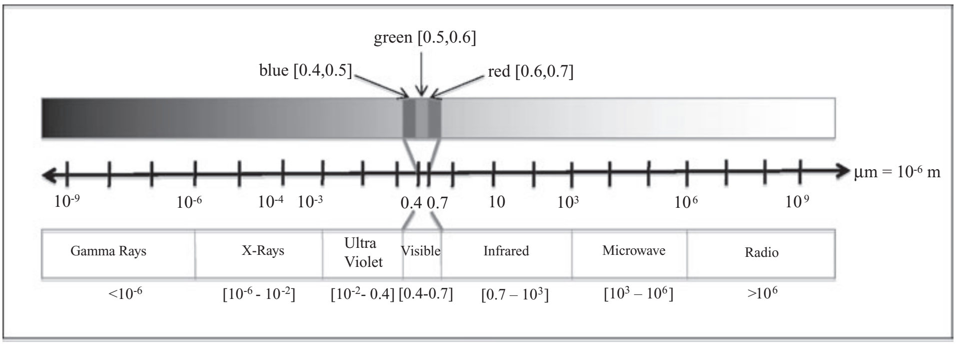

Figure 1.2. Electromagnetic spectrum. See color plates section.

Assuming that the Earth and the Sun behave like blackbodies, their respective dominant wavelengths are 9.7 µm (in the infrared (IR) portion of the spectrum) and 0.5 µm (in the green visible portion of the spectrum). This implies that the energy emitted by the Earth is best observed by sensors which operate in the thermal infrared and microwave portions of the electromagnetic spectrum, while Sun energy which has been reflected by the Earth predominates in the visible, near-infrared and mid-infrared portions of the spectrum. As a consequence, most passive satellite sensing systems operate in the visible, infrared, or microwave portions of the spectrum (Lillesand and Kiefer, 1987; Le Moigne and Cromp, 1999). See Fig. 1.2 for a summary of the above electromagnetic spectrum wavelengths definitions.

1.3.1 Characteristics of satellite orbits

Different orbiting trajectories may be chosen for a satellite depending on many requirements, including the characteristics of the sensors, the data acquisition frequency, the required spatial resolution, the necessary ground coverage, and the type of observed phenomenon. The two most common orbiting modes are usually referred to as *polar orbiting* and *geostationary* (or *geosynchronous*) satellites. A polar orbit passes near the Earth's North and South Poles. Some examples are the Landsat and SPOT satellites whose orbits are almost polar, passing above the two poles and crossing the Equator at a small angle from normal (e.g., 8.2° for the Landsat-4 and Landsat-5 spacecraft). If the orbital period of a polar orbiting satellite keeps pace with the Sun's westward progression compared to the Earth's rotation, these satellites are also called *Sun-synchronous*, that is, a Sun-synchronous satellite always crosses the Equator at the same local Sun time. This time is usually very carefully chosen, depending on the application of the sensing system and the type of features which will be observed with such a system. Atmospheric scientists prefer observations later in the morning to allow for cloud formation, whereas researchers performing land studies prefer earlier morning observations to minimize cloud cover. On the other hand, a geostationary satellite has the same angular velocity as the Earth, so its relative position is fixed with respect to the Earth. Examples of geostationary satellites are the Geostationary Operational Environmental Satellite (GOES) series of satellites orbiting the Earth at a constant relative position above the equator.

1.3.2 Sensor characteristics

Each new sensor is designed for specific types of features to be observed, with requirements that define its spatial, spectral, radiometric, and temporal resolutions. This term of *resolution* corresponds to the smallest unit of granularity that can be measured by the sensor. The spatial resolution corresponds to the area on the ground from which reflectance is integrated to compute the value assigned to each pixel. The spectral resolution relates to the bandwidths utilized in the electromagnetic spectrum, and the radiometric resolution defines the number of "bits" that are used to record a given energy corresponding to a given wavelength. Finally, the temporal resolution corresponds to the frequency of observation, defined by the orbit of the satellite and the scanning of the sensor.

One of the main characteristics of sensors is their signal-to-noise ratio (SNR), or the noise level relative to the strength of the signal. In this context, the term *noise* refers to variations of intensity which are detected by the sensor and that are not caused by actual variations in feature brightness. If the noise level is very high compared to the signal level, the data will not provide an optimal representation of the observed features. At a given wavelength λ, the SNR is a function of the detector quality, as well as the spatial resolution of the sensor and its spectral resolution. Specifically,

$$(S/N)_\lambda = D_\lambda \beta^2 (H/V)^{1/2} \Delta_\lambda L_\lambda, \tag{1.1}$$

where

D_λ is the sensor detectivity (i.e., a measure of the detector's performance quality),
β is the instantaneous field of view,
H is the flying height of the spacecraft,
V is the velocity of the spacecraft,
Δ_λ is the spectral bandwidth of the channel (or spectral resolution), and
L_λ is the spectral radiance of the ground features.

Equation (1.1) demonstrates that maintaining the SNR of a sensor at an acceptable level often requires tradeoffs between the other characteristics of the sensor.