Chapter 1

Introduction

The birth of digital computer has introduced to the society a machine that is much more powerful than human beings in numerical computation. The pertinent question then was whether the human capability of processing non-numerical information received from environment as well as society, of reasoning and decision making based on non-numerical data could be incorporated in the machine with equal or more efficiency. This led to evolution of a new subject called Artificial Intelligence, which has a large area of common interest and motivation with another subject known as Pattern Recognition. Major information received by a human from the environment is visual. Hence, processing of visual information by computer has been drawing a very significant attention of researchers over the last few decades. The process of receiving and analyzing visual information by the human species is referred to as Sight, Perception or Understanding. Similarly, the process of receiving and analyzing visual information by digital computer is called Digital Image Processing and Scene Analysis.

Two broad classes of techniques, viz., Processing and Analysis have evolved in the field of digital image processing and scene analysis. Processing of an image includes improvement in its appearance and efficient representation. The entire process of image processing and analysis starting from the receiving of visual information to the giving out of description of the scene, may be divided into three major stages are given below:

1. Discretization and representation: Converting visual information into a discrete
form; suitable for computer processing; approximating visual information to save storage space as well as time requirement in subsequent processing.

2. **Processing**: Improving Image quality by filtering etc.; compressing data to save storage and channel capacity during transmission.

3. **Analysis**: Extracting Image features; quantifying shapes, registration and recognition.

The Oxford dictionary defines the word *Image* as the optical appearance of something produced in a mirror or through a lens. Image may be formed by other types of radiant energy and devices. However, optical Images are most common and are most important. Amount of light (radiant) energy received at a point of a scene by an observer or by an Image sensor varies with direction and distance of that point. Radiant energy is recorded at corresponding points on a plane to form an image. The Image can be modeled by a continuous function of two or three variables; in the simple case, arguments are coordinates \((x, y)\) in a plane, while if images change in time a third variable is added. The image function values correspond to the brightness at image points. The function value can express other physical quantities as well (temperature, pressure distribution, distance from the observer, etc.). Brightness integrates different optical quantities.

Digital Image Processing and Analysis techniques are used today in a variety of problems. The following are a few major application areas:

1. **Office automation**: optical character recognition; document processing; logo and icon recognition; etc.

2. **Industrial automation**: automatic inspection system; PCB checking; robotics; process control applications; etc.

3. **Bio-medical**: ECG, EEG, EMG analysis; cytological, histological and stereological applications; automated radiology and pathology; X-ray Image analysis; mass screening of medical images such as chromosome slides for detection of various diseases, mammograms, cancer smears; CAT, MRI, PET, SPECT, USG and other
tomography images; routine screening of plant samples; 3-D reconstruction and analysis; etc.

4. **Scientific applications:** High energy physics; bubble chamber and other forms of track analysis; etc.

5. **Criminology:** Finger print identification; human face registration and matching; forensic investigation; etc.

6. **Astronomy and Space applications:** Restoration of images suffering from geometric and photometric distortions; computing close-up picture of planetary surfaces; etc.

7. **Meteorological:** Short-term weather forecasting, long term climatic change detection from satellite and other remote sensing data; cloud pattern analysis; etc.

8. **Information technology:** Facsimile Image transmission, video-conferencing and video phones; etc.

9. **Entertainment and consumer electronics:** HDTV; multimedia and video-editing; etc.

10. **Printing and Graphic arts:** Color fidelity in desktop publishing; art conversation and dissemination; etc.

11. **Military applications:** Missile guidance and detection; target identification; navigation of pilotless vehicle; reconnaissance; and range finding; etc.

12. **Remote Sensing:** Remote sensing systems, particularly those deployed on satellite, provide repetitive and consistent view of the earth that is invaluable to monitoring short-term and long term changes and the impact of human activities. Some of the applications of remote sensing technology are

    - natural resources survey and management
    - estimation related to agriculture
• hydrology, forestry, mineralogy
• urban planning
• registration of satellite images with terrain maps
• monitoring traffic along roads
• environment pollution control

1.1 Image Formation

Objects that are imaged either emit or reflect or transmit radiant energy that propagates through the space. This radiant energy is intercepted by the Image formation system to produce a brightness pattern on a 2D plane, called intensity Image or gray level Image [1]. The entire process has two parts

1. transforming a 3D scene to a 2D plane and

2. assigning an intensity to an Image point that corresponds to a particular point of the scene.

1.1.1 Geometric Model

The Image on the sensing devices like human eye or a camera is intrinsically two dimensional (2D). Such a 2D Image bearing information about brightness points is intensity Image. The real world which surrounds us is three dimensional (3D). The 2D intensity or gray-Image is the result of a perspective projection of the 3D scene, which is modeled by the Image captured by a pin-hole camera, illustrated in Figure 1.1.

Denote a point in the three-dimensional world as a column vector, \( P = [X, Y, Z]^t \) and the projection of this point onto the two dimensional Image plane as \( p = [x, y]^t \). Note that the world and Image points are expressed with respect to their own coordinate systems, and for convenience, the Image coordinate system is chosen to be orthogonal to the Z-axis, i.e., the origins of the two systems are related by a one-dimensional translation along the Z-axis or optical axis. It is straightforward to show from a similar
triangles argument that the relationship between the world and Image point is:

\[ x = -\frac{fx}{Z} \quad \text{and} \quad y = -\frac{fy}{Z} \]

where \( f \) is the displacement of the Image plane along the Z-axis, is often referred to as the focal length. These equations are frequently referred to as the perspective projection equations. Although non-linear in nature, the perspective projection equations may be expressed in matrix form using the homogeneous equations:

\[
\begin{pmatrix}
    x_s \\
    y_s \\
    s
\end{pmatrix} =
\begin{pmatrix}
    -f & 0 & 0 & 0 \\
    0 & -f & 0 & 0 \\
    0 & 0 & 1 & 0
\end{pmatrix}
\begin{pmatrix}
    X \\
    Y \\
    Z \\
    1
\end{pmatrix}
\]

where \( s \) is homogenous scale factor, \( s \neq 0 \). The final Image coordinates are given by \([x, y] = [x_s, y_s] / s\). These are called nonhomogeneous coordinates. If \( s = 0 \), a point \( p = [x, y, 0] \) is regarded as located at infinity is called an ideal point. The set of all the points at infinity is called a line at infinity.
1.1.2 Radiometric Model

Artificial vision sensors measure the amount of received light energy in individual pixels as the result of interaction among various materials and light sources; the value measured is called gray-level (or brightness). Radiometry is a branch of physics that deals with the measurement of the flow and transfer of radiant energy. The gray level corresponding to a point on a 3D surface depends, on the shape of the object, its reflectance properties, the position of the viewer, and properties of the illuminants. From viewer’s point of view, the surface of an object can reflect energy into a half-sphere differently into different directions. The spatial angle is given by the area on the surface of the unit sphere that is bounded by a cone with an apex in the center of the sphere. The whole half-sphere corresponds to the spatial angle $2\pi sr$. A small area $A$ at distance $R$ from the origin and with angle between the normal vector to the area and radius vector between the origin and the area corresponds to the spatial angle $\Omega$.

$$\Omega = \frac{A \cos \theta}{R^2}$$

Irradiance $I$ [Wm$^{-2}$] describes the power of the light energy that falls onto a unit area of the object surface, $I = \delta \Phi \delta A$, where $\delta A$ is an infinitesimal element of the surface area; $\Phi$[W] is radiant flux, the basic radiometric quantity; the corresponding photometric quantity is illumination.

Radiance [Wm$^{-2}$sr$^{-1}$] is the power of light that is emitted from a unit surface area into some spatial angle, and the corresponding photometric quantity is called brightness. Brightness is used in Image analysis to describe the quantity that the camera measures.

$$f(x, y) = R(x, y) \times I(x, y)$$ \hspace{1cm} (1.2)

where $f(x, y)$ is scene radiance at the point $(x, y)$, while $R(x, y)$ and $I(x, y)$ are reflectance and irradiance respectively at that point.
1.2 Satellite Image Acquisition

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 [1]. One way to achieve the retrieval of information in remote sensing applications is by the use of electromagnetic energy sensors that are currently operated from airborne and space borne platforms to assist in inventorying, mapping and monitoring earth resources. The major optical spectral regions used for earth remote sensing are shown in Table 1.1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Wavelength range</th>
<th>Radiation Source</th>
<th>Surface property of interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible(V)</td>
<td>0.4 – 0.7μm</td>
<td>solar</td>
<td>reflectance</td>
</tr>
<tr>
<td>Near Infrared(NIR)</td>
<td>0.7 – 1.1μm</td>
<td>solar</td>
<td>reflectance</td>
</tr>
<tr>
<td>Short Wave Infrared(SWIR)</td>
<td>1.1 – 2.5μm</td>
<td>solar,thermal</td>
<td>reflectance, temperature</td>
</tr>
<tr>
<td>MidWave Infrared(MWIR)</td>
<td>3-5 μm</td>
<td>solar</td>
<td>temperature</td>
</tr>
<tr>
<td>Thermal Infrared (TIR)</td>
<td>8-14 μm</td>
<td>thermal</td>
<td>reflectance</td>
</tr>
<tr>
<td>Microwave,radar</td>
<td>1 mm-1m</td>
<td>artificial</td>
<td>roughness</td>
</tr>
</tbody>
</table>

Figure 1.2: Optical Remote sensing schemes

Optical remote sensing as shown in Figure 1.2, makes use of visible, near infrared and short-wave infrared sensors to form images of the earth’s surface by detecting the solar radiation reflected from targets on the ground. Different materials reflect and absorb
differently at different wavelengths. Thus, the targets can be differentiated by their spectral reflectance signatures in the remotely sensed images. Optical remote sensing systems are classified into the following types, depending on the number of spectral bands used in the imaging process.

- **Panchromatic Imaging System:** The sensor is a single channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincides with the visible range, then the resulting Image resembles a *black-and-white* photograph taken from space. The physical quantity being measured is the apparent brightness of the targets. The spectral information or *color* of the targets is lost. Examples of panchromatic imaging systems are:
  
  1. IKONOS PAN
  2. SPOT HRV-PAN

- **Multispectral Imaging System:** The sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band. The resulting Image is a multilayer Image which contains both the brightness and spectral (colour) information of the targets being observed. Examples of multispectral systems are:
  
  1. LANDSAT MSS
  2. LANDSAT TM
  3. SPOT HRV-XS
  4. IKONOS MS
  5. RESOURCESAT LISSIII

- **Superspectral Imaging Systems:** A superspectral imaging sensor has many more spectral channels (typically > 10) than a multispectral sensor. The bands have narrower bandwidths, enabling the finer spectral characteristics of the targets to be captured by the sensor. Examples of superspectral systems are:
1. MODIS

2. MERIS

- Hyperspectral Imaging Systems: A hyperspectral imaging system is also known as an *Imaging Spectrometer*. It acquires images in about a hundred or more contiguous spectral bands. The precise spectral information contained in a hyperspectral image enables better characterization and identification of targets. Hyperspectral images have potential applications in such fields as precision agriculture (e.g. monitoring the types, health, moisture status and maturity of crops), coastal management. An example of a hyperspectral system is: Hyperion on EO1 satellite.

Normal camera acquires images only in visible range while satellite images have 4 to more than 100 spectral bands. Normal images give information about reflectance and absorption of surface imaged. Satellite images give information about reflectance, absorption and emission property of the surface and the distance between target and sensor is more than 22,500 km (in case of geostationary orbiting satellite) and 800-900 km in polar orbiting satellites. As far as normal Images are concerned they are captured from short distance.

1.2.1 Solar Irradiation

Optical remote sensing depends on the sun as the sole source of illumination. The solar irradiation spectrum above the atmosphere can be modeled by a black body radiation spectrum having a source temperature of 5900°K, with a peak irradiation located at about 500 nm wavelength. Physical measurement of the solar irradiance has also been performed using ground based and space borne sensors. After passing through the atmosphere, the solar irradiation spectrum at the ground is modulated by the atmospheric transmission windows, illustrated in Figure 1.3.
1.2.2 Spectral Reflectance Signature

When solar radiation hits various objects on the earth surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing. The Figure 1.4 shows the typical reflectance spectra of clear water, bare soil and vegetation.
The reflectance of clear water is generally low. It reflects only in the visible band of spectrum. As water has almost no reflection in the NIR region, it is very distinct from other surfaces. Thus, water bodies are clearly delimited as dark areas (low pixel values) in NIR band Images. The reflectance of bare soil generally depends on its composition. In the example shown, the reflectance increases monotonically with increasing wavelength. Hence, it should appear yellowish-red to the eye.

Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared Image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region which gives rise to the green color of vegetation. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves as in Figure 1.4. Hence, vegetation can be identified by the high NIR but generally low visible reflectance. This property has been used in early reconnaissance missions during war times for camouflage detection.

1.2.3 Atmospheric Interference

The atmosphere is an unavoidable influence in satellite remote sensing. It scatters and absorbs radiation between the sun and the earth along the solar path, and again between
the earth and the sensor along the view path.

The areas of the EM spectrum that are absorbed by atmospheric gases such as water vapor, carbon dioxide, and ozone are known as absorption bands. In Figure 1.5, absorption bands (shown in brown) are represented by a low transmission value that is associated with a specific range of wavelengths.

In contrast to the absorption bands, there are areas of the EM spectrum (shown in green in Figure 1.5) where the atmosphere is transparent (little or no absorption of energy) to specific wavelengths. These wavelength bands are known as atmospheric windows since they allow the energy to easily pass through the atmosphere to Earth’s surface. Most remote sensing instruments operate in one or more of these windows by making their measurements with detectors tuned to specific wavelengths that pass through the atmosphere. Fortunately, a great deal of the visible light passes through the atmosphere. Atmosphere is also transparent in certain ranges of the near-infrared spectrum.

![Figure 1.5: Atmospheric Windows](from oneonta.edu)

### 1.3 Processing of Satellite Images

Satellite-based remote sensing devices are a constant source of multispectral images and the same time cluster of satellites provides multisource Images depending on data used
from Landsat, NOAA, SPOT, INSAT, IRS, etc.

The information (digital value of a pixel) provided by individual sensor is incomplete, inconsistent, or imprecise for many applications. Additional sources may provide complementary data; fusion of different information can produce a better understanding of the observed site, by decreasing the uncertainty related to the single source. Multitemporal and multisensor high resolution data are often fused together to acquire complementary information to interpret the objects accurately. Image registration and Image normalization are two important preprocessing operations in processing of high resolution, multi-temporal or multi-sensor Images. Among aspects of Image preprocessing for land cover change detection and Earth observation monitoring applications, there are two essential requirements: Image registration and Radiometric normalization. Image registration and radiometric normalization can transform multi-temporal or multi-sensor data into identical geometric and radiometric bases respectively [2-3].

1.3.1 Geometric Registration

Spatial registration of multidate or multisensor images is required for many applications in remote sensing, such as change detection, the construction of image mosaics, Digital Elevation Model generation from stereo pairs, and orthorectification. Registration is the process of geometrically aligning two or more Images of the same scene acquired at different times, or with different sensors, or from different view points. It is one of the crucial Image processing operations in remote sensing. Without a common geometric base, the derived information from a single remote sensing Image cannot be associated with other spatial information, making precise geo-spatial analysis possible; even comparisons among remote sensing Images cannot be implemented if those Images do not have the same geometric base. Applications utilizing multitemporal, multisensor remotely sensed data are dependent on the accurate registration of the data into a common spatial framework.
1.3.2 Radiometric Normalization

Radiometric correction of remotely sensed data normally involves the processing of digital Images to improve the fidelity of the brightness value magnitudes (as opposed to geometric correction which involves improving the fidelity of relative spatial or absolute locational aspects of Image brightness values). The main purpose for applying radiometric corrections is to reduce the influence of errors or inconsistencies in Image brightness values that may limit one’s ability to interpret or quantitatively process and analyze digital remotely sensed Images [4].

Due to variations in atmospheric conditions, look/view angles, or sensor parameters that occur between acquisition dates, scenes of the same target area acquired at different times have been nearly impossible to compare in an automated fashion without performing the image normalization. Even visual comparison of these images may be difficult [5-6]. There are two kinds of image radiometric normalization: namely absolute and relative. The absolute radiometric correction can convert the digital counts in satellite image data to radiance at the surface of the Earth [7]. The images from different sensors can be compared by using the radiance. The absolute radiometric correction tends to be more accurate than the relative correction, but it needs sensor parameters, atmospheric refraction parameters and other data that are difficult to obtain. Thus, the difficulty in obtaining the above accurate atmospheric and sensor parameters, makes relative radiometric normalization an attractive alternative. The relative radiometric normalization applies one image as a reference and adjusts the radiometric properties of the subject image to match the reference image [8]. The normalized image appears to have been acquired under the same solar and atmospheric conditions as the reference image.

1.4 Problem Definition

High resolution satellite imagery provides researchers with information sources necessary for use in many change detection applications. However, problems occur when applying conventional traditional Image processing methods to process and analyze these high
resolution Images. The variations in spectral response of various Earth surface materials (soil, rock, vegetation, water) enable discrimination and identification of landscape properties, depending on the spatial and spectral resolution of the sensor. Relative correspondence of Image brightness magnitudes is desired for pixels: (1) within a single Image, (2) between Images (e.g. adjacent, overlapping frames), (3) between spectral bands of Images, and (4) between Image dates. The color and texture appearances of the same surface vary significantly with the changes in illumination and sensor properties. Primary reason for applying radiometric corrections to remotely sensed data is to achieve consistency in relative Image brightness and absolute quantification of brightness values. The motivation behind this study is to suggest simple and effective computer-assisted methods for radiometric correction to provide more accuracy in satellite Image interpretation. The prime objective of research is radiometric registration of multitemporal data sets to correct for atmospheric effects and anisotropic effects acting within-scene and between spatially concurrent or adjacent scenes.

The objectives of this study are:

- To develop/improve Image preprocessing technique for change detection in multitemporal satellite Images, i.e. the Image processing operations that are applied before the use of a change detection algorithm.
- To evaluate the performance of radiometric normalization methods reported in literature for multispectral imagery.
- To propose new transform domain techniques of relative radiometric correction.
- To study application of relative radiometric correction for change detection in multitemporal satellite Images.

### 1.5 Contribution to the Thesis

In an automatic change detection process, radiometric normalization and geometric registration of temporal Images are first two operations that must be performed on Images.
Both these operations affect the final accuracy of change detection.

- We proposed automated radiometric correction process that identifies the subset of non-changing pixels automatically by using correlation and uses a parametric smoother to adjust a nonlinear mapping in order to minimize the effects of influences of radiometric differences on image interpretation. Normalization by means of ordinary linear least squares regression is compared with normalization by polynomial regression up to 5\textsuperscript{th} order.

- A novel approach has been introduced for radiometric correction of multitemporal satellite imagery in frequency domain using Fourier and Wavelet transforms. Wavelet transform is applied to each band of multispectral Images taken at different time. Each band is decomposed into four subbands. Subbands of subject image are regressed against analogous subbands of reference image using linear least squares regression. After regressing Wavelet coefficients of subject image, inverse Wavelet transform is applied to obtain corrected image.

A method of radiometric correction has been explored in frequency domain (Fourier and Wavelet), Pseudo-Invariant Feature regression, and this process identifies landscape elements such as vegetation whose reflectance values are not constant over time based on spatial frequency of vegetation. It takes advantage of vegetation being typically high frequency area, can be removed by low pass filter. In spatial domain, PIF set is determined from band ratio NIR/red and normalized image look very different from reference image. Also, some floating objects in the river with reflectance similar to nonvegetation area may be included in PIF set. A novel transform domain algorithm for haze correction using Fourier transform is presented. Water bodies being low frequency region, can be extracted using low pass filter in frequency domain. Fourier coefficients of filtered reference image are subtracted from Fourier coefficients of filtered subject image. Inverse Fourier transform gives haze distribution. Haze correction in spatial domain method uses dark object subtraction, assumes a constant haze value throughout the entire Image.
The proposed technique considers frequency dependance of haze effect so fourier
domain method is a powerful approach.

• A technique for correction of cloudy Images is presented. Cloud detection is
achieved by using Average Brightness Threshold (ABT) algorithm and detected
cloud is removed and replaced with pixels predicted by regression. No patches are
seen in place of cloud. The earlier techniques where the detected cloud is removed
and replaced with data from another images of the same area patches are observed
in place of cloud.

• For change detection a method is recommended using Radon transform. Radon
transform is applied on Near Infrared band of multispectral Images taken at dif­
ferent times. Projections are taken for $\theta = 0$ to 180. Projections of one image are
subtracted from projections of another image. Inverse radon transformation is ap­
plied on difference of projections. The resultant is observed with high brightness in
the direction for changed land area. Threshold is applied for detecting boundaries
of the changed area. The proposed method is compared with Image Differencing
technique and Image Regression method. We found that this technique works well
for finding change in boundaries of water bodies; also direction of change can be
detected. No other method detects direction of change.

1.6 Organization of the Thesis

The thesis is organized in the following manner:

Chapter 1 provides a concise introduction to Image processing and its importance
in Remote Sensing. It introduces Image formation model, satellite Image acquisition,
preprocessing of satellite images and general concepts of remote sensing. It explains the
main motivation of the research described in this thesis and its structure.

Chapter 2 illustrates the comprehensive literature survey to review the different ra­
diometric correction techniques. It describes the typical normalization methods and
performance evaluation of these methods. Finally the significant conclusion drawn from
literature survey are presented and based on this, the motive for modification and proposed has been defined.

Chapter 3 is dedicated to relative radiometric correction of satellite Images by using polynomial regression method and does the comparison of linear and polynomial regression methods in terms of error criteria applied with the help of graphs.

Chapter 4 explores the use of transform domain approach to relative radiometric correction. It focuses on use of Fourier and Wavelet transform in extracting water bodies and removing vegetation. Proposed methods are compared with spatial domain methods.

Chapter 5 describes radiometric correction of cloudy satellite Images. Cloud detection is achieved by using Average Brightness Threshold (ABT) algorithm and detected cloud is removed and replaced with pixels predicted by regression.

Chapter 6 discusses Radon Transform based technique of change detection. For change detection a method is recommended using Radon transform. The proposed technique works well for finding change in boundaries of water bodies; also direction of change can be detected. No other method detects direction of change.

Chapter 7 finally concludes this work by giving brief summary and critique of the findings as well as identifying areas for future research.