EE 463 INTRODUCTION TO REMOTE SENSING

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MAIN REFERENCE BOOKS:

1. NAME : Remote Sensing Digital Image Analysis: An Introduction
   AUTHORS : Xiuping Jia, John A. Richards, D. E. Ricken (Editor)
   PUBLISHER : Springer Verlag
   ISBN : 3540648607

	EDITION	: 3rd edition (June 1999)
2.	NAME	: Introductory Digital Image Processing: A Remote Sensing Perspective
	AUTHOR	: John R. Jensen
	PUBLISHER	: Prentice Hall
	ISBN	: 0132058405
	EDITION	: 2 edition (August 25, 1995)

GRADING:	1	MID TERM EXAM (IN CLASS)	:	%40
	1	FINAL EXAM (IN CLASS)	:	%50
		ATTENDANCE	:	%05
	1	HW	:	%05
		TOTAL	:	%100

1. DESCRIPTION AND APPLICATION FIELDS OF REMOTE SENSING

See Additional Pages – 1, 1.a, 2, 3

Some Definitions of Remote Sensing:

- Group of Techniques for collecting image or other forms of data about an object from measurements made at a distance from the object and the processing and analysis of analysis of the data.
- Measurement and analysis of electromagnetic radiation reflected from, transmitted through, or absorbed and scattered by the atmosphere and by material at or near the land surface, for the purpose of understanding and managing Earth's resources and environment.
- The science and art of obtaining useful 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.

Basic Elements of Remote Sensing:

1. Source of Energy (Illumination or Incident Energy): e.g. Sun, Laser, Microwave, Thermal Emission

2. Radiation Characteristics of the Source of Energy: e.g. Size, Power, Spectral Content, Coherence

3. Medium of Propagation: e.g. Atmosphere, Dielectric Material

4. Propagation Factors: e.g: Attenuation (Scattering, Absorption), Dispersion

5. Target or Object: e.g. Earth, Sea, Vegetation, Oil, Flood

6. Interaction of Energy with the Target: e.g. Reflection, Transmission, Absorption

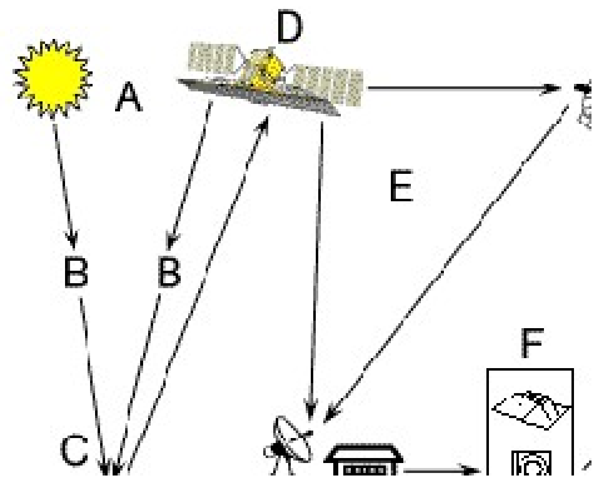
7. Remote Sensors: e.g. Aircraft, Satellite, Ground-based

8. Image Data Formation and Recording: e.g Photography, Digital Image

9. Image Data Processing: e.g: Eye-processing, Computer processing

10. Analysis of Processed Image for Specific Application: e.g. Visually, Electronically (Digital) extracting information about the target

An Example of a Remote Sensing Configuration



1, 2 ⇒ A

3, 4 ⇒ B

5, 6 ⇒ C

7, 8 ⇒ D, E

9, 10 ⇒ F, G

Some Applications of Remote Sensing

- Mapping
  - Planimetric (in x,y plane). e.g. general landscape information, urban mapping, transportation networks
  - Digital Elevation Model. e.g. integration into programming of cruise missiles to guide them over the terrain, route planning, telecommunications planning, volcanic inflation before eruption, relative earth movements caused by earthquakes
  - Topographic and Baseline Thematic. e.g. combination of interpretations of ground cover data and land use with topographic info (like elevation contours) and planimetry which becomes an optimal tool for resource management.

- Agriculture

- Vegetation Type and Growth Observation (Both quality and quantity)
- Crop Identification, Monitoring

- Weather
    - Forecast
    - Recording
    - Pollution Detection and Monitoring
    - Storm Forecast

- Hydrology, Oceans and Coastal
    - Flood Delineation
    - Soil Moisture
    - Ice Motion
    - Understanding Ocean Dynamics (e.g. fish stock assessment, ship routing)
    - Oil Spill Detection

- Forestry
    - Species Identification and Inventory
    - Fire Detection
    - Burn Delineation (Şeklini Çizmek)

- Geology
    - Structural Mapping and Terrain Analysis. e.g. mineral exploration, potential hazard monitoring and identification

- Others
    - Medical Applications
    - In the Sea Applications (Fish Mapping)
    - Micro Remote Sensing Applications

2. CHARACTERISTICS OF DIGITAL IMAGE DATA

- Remote sensing image data of earh's surface collected from aircraft or spacecraft is in digital format (if not then it is digitized into discrete data).

  Data is composed of:

  - **Spatially**: Dicrete picture elements, or pixels

  - **Radiometrically:** Quantised discrete brightness levels

- Characteristics of image is related to the wavelength band in which the measurement is taken. e.g:

  - Spatial disposition of reflected solar radiation in the ultraviolet, visible and near-to-middle infrared (passive system since the source is external)

  - Spatial distribution of energy emitted by the earth itself in the thermal infrared

- Measurements of relative energy returned from the earth's surface where the source in microwave is transmitted by the airplane (active system because the energy source is provided by the remote sensing platform)

- Important factors for Data Handling and Analysis:

  - Number of Spectral Measurements (spectral bands) by a particular sensor

  - Location of Spectral Measurements (spectral bands) by a particular sensor

- **Resolution:**

  - **Spatial resolution** is described by pixel size, in equivalent ground metres

  - **Radiometric resolution** (Dynamic range or signal-to-noise ratio) is described by the range and the number of discrete brightness values. Expressed as the number of binary digits or bits necessary to represent the range of brighness values. e.g. 8 bit radiometric resolution → 256 brightness levels
    4 bit radiometric resolution → 16 brightness levels

  - **Spectral resolution** describes the ability of a sensor to define narrow (fine) wavelength intervals. Finer the spectral resolution, narrower the wavelength range for a particular channel or band.

    e.g. Broad classes like water and vegetation can be separated using very broad wavelength ranges, visible and near infrared.
    However, more specific classes like different rock types require finer wavelength ranges to separate them

See Additional Page 3.A

  - **Temporal resolution** of a remote sensing system to image the exact same area at the same viewing angle a second time is equal to the revisit period (length of time it takes for a satellite to complete one entire orbit cycle, usually several days).

    Temporal resolution is important in:
    i) imaging of short lived phenomena like floods, oil slicks or
    ii) imaging in cloudy weather conditions or
    iii) in observing vegetation growth

- **Volume of Data** received from a particular sensor which is **to be processed**, consists of:

  - Frame size of an image, in equivalent ground kilometres

  - Number of spectral bands

  - Radiometric resolution

  - Spatial resolution

- Repeating measurements in time

3. Spectral Ranges Used

Frequency Spectrum:

See Additional Pages 4, 5

- Principally remote sensing systems can be in a wide spectral range. However limited due to:
    - Technical possibilities in general
    - Spectral reflectance characteristics (Reflectance versus wavelength) of the material of interest

See Additional Page 6

- Atmospheric Scattering and Absorption
- Significance of the data acquired at that frequency

- Some frequencies (wavelengths = $\lambda = c / f$) of interest::
    - Visible / infrared (λ= 0.4μm – 12 μm): Earth resources.e.g cellular structure and moisture content of vegetation, moisture contents of soil
    - Thermal infrared (far infrared) (5.5 μm – 5 mm): Heat capacity and other thermal properties of the surface and the nearby surface
    - Microwave (f = 1GHz – 10GHz) - Active imaging using radars: Surface roughness and electrical properties
    - 20GHz – 60 GHz: Atmospheric oxygen and water vapour

See Additional Pages 7, 8

- **Blackbody radiation**

See Additional Page 9, 9.a

- Real objects are not perfect blackbody radiators, they emit energy lower than blackbody rediation
- Emittance is proportional to (Object radiation / Blackbody Radiation) is wavelength dependent.

- **Systems are optimized for certain wavelength range based on the application**

Remote Sensing Satellites

Satellites are man made moons.

See Additional Page 10, 10A, 11, 12

Satellite Launch Vehicle

See Additional Page 13

List of Remote Sensing Satellites

See Additional Page 14

Some parameters of remote sensing satellites

- **Satellite Orbits**

See Additional Page 15,16

Orbit is the path traced out by by a satellite in space as it moves around the earth.

1. Circular orbit

- Orbit whose path is a circle centered around the center of earth
- Usually used in remote sensing
- Shape of circular orbits depend on two parameters:

  i) **Orbital altitude** – Height above the surface of earth

  ii) **Inclination Angle** – The angle between satellite's orbital plane and earth's equatorial plane.

  Inclination angle of an orbital plane also determines the observation area of the satellite on earth. E.g. inclination angle = 30° means observation area is bounded by +/- 30° latitude (i.e. the tropical region)

  Satellites with orbits of inclination angle less than 90° rotate around the world in the same sense as the earth itself rotates while inclination angle more than 90° means orbiting is in the opposite sense to earth's rotation

2. Low Earth Orbit (LEO)

- When a satellite circles close to Earth we say it's in Low Earth Orbit (LEO).
- Satellites in LEO have altitudes of 200 - 500 - 933 miles (320 - 800 - 1500 kilometres)

- Because they orbit so close to Earth, they must travel very fast so gravity won't pull them back into the atmosphere.

- Satellites in LEO speed along at 17,000 miles per hour (27,359 kilometres per hour). They can circle Earth in about 90 minutes.

- A Low Earth Orbit is useful because of its nearness to Earth. Satellites that observe our planet, like Remote Sensing and Weather satellites, often travel in LEOs because from this height they can capture very detailed images of Earth's surface.

3. Polar orbit

- Polar orbit's inclination angle is near 90° (near polar orbit)

- A Polar orbit is a particular type of Low Earth Orbit. The only difference is that a satellite in polar orbit travels a north-south direction (descending from north-south, ascending from south-north), rather than the more common east-west direction.

- Polar orbits are useful for viewing the planet's surface. As a satellite orbits in a north-south direction, Earth spins beneath it in an east-west direction. As a result, a satellite in polar orbit can eventually scan the entire surface

- Between successive orbits the Earth rotates 22.5° (In 24 hrs rotates 360° so in 1,5 hrs (in one orbit rotation) rotates 22.5°)

- Therefore 360°/22.5° = 16 orbits are required to scan totally the Earth's surface.

- For this reason, satellites that monitor the global environment, like remote sensing satellites and certain weather satellites are almost always in polar orbit.

- Tracking of these fast satellites by the ground stations has been a major obstacle which is now being overcome.

4. Geosynchronous orbit

- Has a fixed position relative to the surface of earth

- 35,786.1 km altitude

- Inclination angle is not zero

5. Geostationary orbit (GEO)

- It is geosynchronous orbit with zero inclination angle

- Satellite is fixed over one longitude at the equator. (In practice it moves slightly and requires periodic orbit adjustments

- Used in meteorlogy and communications (used in TV transmission, not effective in mobile communications
- No tracking from the ground station is needed

6. Sun synchronous orbit

- Inclination and altitude is such that a satellite passes over a given site always at the same local time

7. Elliptical orbit

- Moves in north-south direction
- Mostly for communications around the north and south pole areas

- **Period of satellites**

  Time spent for completion of one orbital revolution

- **Repeat Cycle**

  Number of revolutions around the orbit before the satellite passes over a given site

- **Dynamic Range**

  Number of bits representing the brightness levels

- **Bands, Channels**

  Spectral Band of frequencies (assigned to channels) used in sensing

- **Nadir Mode**

  Mode of measurement in which the the line of sight of a sensor points from the orbit downward to the earth's surface

- **Limb Mode**

  Mode of measurement in which the line of sight of a sensor points from the orbit tangentially into the earth's atmosphere

- **Field of View (FOV)**

See Additional Page 17,18

Scan angle (in degrees) either side of nadir over which data is recorded

In the range of 11° - 15° for landsat. In the range of 70° - 90° in aircraft scanning

- **Instantaneous Field of View (IFOV)**

See Additional Page 17, 18

Solid angle (in milliradians) extending from a detector to the area on the ground (ground pixel) it measures at any instant

- **Swath Width**

See Additional Page 17, 18

Width of the area scanned by the sensor

4. Satellite Sensors

See Additional Page 19

- Types of sensors used:

See Additional Page 20

- Wavelength Band of sensors used:

See Additional Page 21

- Optical Sensor Characteristics:

See Additional Page 22 (Two pages)

- Scanners:

  - Cross-track scanner See Additional Page 23 Fig(A)
  - Along-track scanner See Additional Page 23 Fig(C)

4.1. Weather Satellite Sensors

See Additional Page 24 (Two pages)

- Weather Satellites have almost the same band of frequencies as the Earth Resource Satellite Sensors
- Spatial Resolution of Weather Satellite Sensors (1 km x 1km) are coarser than Earth Resource Satellite Sensors' Spatial Resolution (< 100 m)
- Weather Satellite Sensors provide large areal coverage
- Performs weather monitoring and forecasting
- In near-polar orbits, providing repetitive coverage of global weather patterns
- Temporal resolutions are generally quite high, providing frequent observations of the Earth's surface, atmospheric moisture, and cloud cover, which allows for near-continuous monitoring of global weather conditions, and hence - forecasting. Here we review a few of the representative satellites/sensors used for meteorological applications:

GOES

- Latest is GOES 12

- The GOES (Geostationary Operational Environmental Satellite) System is designed by NASA for the National Oceanic and Atmospheric Administration (NOAA) to provide the United States National Weather Service with frequent, small-scale imaging of the Earth's surface and cloud cover.

- These satellites are part of a global network of meteorological satellites spaced at approximately 70° longitude intervals around the Earth in order to provide near-global coverage.

- Two GOES satellites, placed in geostationary orbits 36000 km above the equator

- Eeach view approximately one-third of the Earth.

- One is situated at 75°W longitude and monitors North and South America and most of the Atlantic Ocean.

- The other is situated at 135°W longitude and monitors North America and the Pacific Ocean basin.

- Together they cover from 20°W to 165°E longitude. This GOES image covers a portion of the southeastern United States, and the adjacent ocean areas where many severe storms originate and develop. This image shows Hurricane Fran approaching the southeastern United States and the Bahamas in September of 1996.

- The second generation of GOES satellites measure emitted and reflected radiation from which atmospheric temperature, winds, moisture, and cloud cover can be derived.

- With GOES-8 (launched 1994). They provide near-continuous observation of the Earth allowing more frequent imaging (as often as every 15 minutes). This increase in temporal resolution coupled with improvements in the spatial and radiometric resolution of the sensors provides timelier information and improved data quality for forecasting meteorological conditions.

- GOES-8 and the other second generation GOES satellites have separate imaging and sounding instruments.

- The imager has five channels sensing visible and infrared reflected and emitted solar radiation.

- The infrared capability allows for day and night imaging.

- Sensor pointing and scan selection capability enable imaging of an entire hemisphere, or small-scale imaging of selected areas. The latter allows meteorologists to monitor specific weather trouble spots to assist in improved short-term forecasting.

- The imager data are 10-bit radiometric resolution

- Image data can be transmitted directly to local user terminals on the Earth's surface.

- The following table describes the individual bands, their spatial resolution, and their meteorological applications.

GOES Bands

Band	Wavelength Range	Spatial Resolution	Application
1	0.52 - 0.72 (visible)	1 km	cloud, pollution, and haze detection; severe storm identification
2	3.78 - 4.03 (shortwave IR)	4 km	identification of fog at night; discriminating water clouds and snow or ice clouds during daytime; detecting fires and volcanoes; night time determination of sea surface temperatures
3	6.47 - 7.02 (upper level water vapour)	4 km	estimating regions of mid-level moisture content;tracking mid-level atmospheric motion
4	10.2 - 11.2 (longwave IR)	4 km	identifying cloud-drift winds, severe storms, and heavy rainfall
5	11.5-12.5 (IR window sensitive	4 km	identification of low-level moisture; determination of sea surface temperature; detection of airborne dust and volcanic ash

- Sixth band available on GOES-12(M) at 12.9 - 13.8 um (lower level (CO2) temperature) at 8 km, useful for determination of cloud characteristics (such as cloud top pressure).

- The last image (from GOES-12) is a full disk (covering total world in one disc shape) from 25 September 2001

Sounders in GEOS

- Sounders measure the parameters like atmospheric temperature and moisture in the vertical atmospheric profile (imagers measure horizontally)

- The 19 channel sounder measures emitted radiation in 18 thermal infrared bands and reflected radiation in one visible band.

- These data have a spatial resolution of 2 km in the infrared and 1 km in the visible

- 13-bit radiometric resolution

- Sounder data are used for surface and cloud-top temperatures, multi-level moisture profiling in the atmosphere, and ozone distribution analysis.

NOAA AVHRR

- Meteorological, as well as other, applications.

- Sun-synchronous, near-polar orbits (830-870 km above the Earth)

- Provide complementary information to the geostationary meteorological satellites

- Two satellites, each providing global coverage, work together to ensure that data for any region of the Earth is no more than six hours old. One satellite crosses the equator in the early morning from north-to-south while the other crosses in the afternoon.

- The primary sensor on board the NOAA satellites, used for both meteorology and small-scale Earth observation and reconnaissance, is the Advanced Very High Resolution Radiometer (AVHRR).
- AVHRR sensor detects radiation in the visible, near and mid infrared, and thermal infrared portions of the electromagnetic spectrum

- Swath width of 3000 km.

NOAA AVHRR BANDS

Band	Wavelength Range	Spatial Resolution	Application
1	0.58 - 0.68 (red)	1.1 km	cloud, snow, and ice monitoring
2	0.725 - 1.1 (near IR)	1.1 km	water, vegetation, and agriculture surveys
3	3.55 -3.93 (mid IR)	1.1 km	sea surface temperature, volcanoes, and forest fire activity
4	10.3 - 11.3 (thermal IR)	1.1 km	sea surface temperature, soil moisture
5	11.5 - 12.5 (thermal IR)	1.1 km	sea surface temperature, soil moisture

AVHRR DATA

Either
- Can be transmitted directly to the ground and viewed as data are collected

OR.
- Recorded on board the satellite for later transmission and processing

AVHRR Data Formats

AVHRR data can be acquired and formatted in four operational modes, differing in resolution and method of transmission.

Format	Spatial Resolution	Transmission and Processing
APT (Automatic Picture Transmission)	4 km	low-resolution direct transmission and display
HRPT (High Resolution Picture Transmission)	1.1 km	full-resolution direct transmission and display
GAC (Global Area Coverage)	4 km	low-resolution coverage from recorded data
LAC (Local Area Coverage)	1.1 km	selected full-resolution local area data from recorded data

- AVHRR sensors are widely used for weather system forecasting and analysis, also used for observation and monitoring of land features

Other Weather Satellites

- DMSP (Defense Meteorological Satellite Program)
- GMS satellite series
- Meteosat satellites.

4.2. Earth Resource Satellite Sensors in the Visible and Infrared

Landsat

- First satellite designed specifically to monitor the Earth's surface
- Combination of sensors with spectral bands tailored to Earth observation
- Functional spatial resolution
- Good areal coverage (swath width and revisit period).
- Near-polar, sun-synchronous orbits
- Later landsat satellites are at around 700 km and have revisit periods of 16 days
- Equator crossing times in the morning to optimize illumination conditions
- Landsat Sensors:

  i) Return Beam Vidicon (RBV) camera systems

ii) MultiSpectral Scanner (MSS) systems

iii) Thematic Mapper (TM) (Replaced MSS after Landsat 4 in 1992)

- Each of these sensors collected data over a swath width of 185 km, with a full scene as 185 km x 185 km.

TM (Thematic Mapper) sensor

See additional page 25

- In Landsat (Replaced MSS after Landsat 4 in 1992)
- Polar orbit
- Spatial resolution of TM is 30 m for all but the thermal infrared
- Spatial resolution of TM is 120 m for thermal infrared
- Swath width is 185 km
- All channels are recorded over a range of 256 digital numbers (8 bits)
- Uses an oscillating mirror which scans during both the forward (west-to-east) and reverse (east-to-west) sweeps of the scanning mirror
- 16 detectors for the non-thermal channels
- 16 scan lines are captured simultaneously for each non-thermal spectral band. İ.e. 16 scan lines x 30 m per line spacing = 480 meter strips are swept across the satellite path
- 4 scan lines are captured simultaneously for thermal spectral band.

TM Bands

Channel	Wavelength Range (μm)	Application
TM 1	0.45 - 0.52 (blue)	soil/vegetation discrimination; coastal mapping; cultural/urban feature identification
TM 2	0.52 - 0.60 (green)	green vegetation mapping (measures reflectance peak); cultural/urban feature identification
TM 3	0.63 - 0.69 (red)	vegetated vs. non-vegetated and plant species discrimination (plant chlorophyll absorption); cultural/urban feature identification
TM 4	0.76 - 0.90 (near IR)	identification of plant/vegetation types, health, and biomass content; water body delineation; soil moisture
TM 5	1.55 - 1.75 (short wave IR)	sensitive to moisture in soil and vegetation; discriminating snow and cloud-covered areas

TM 6	10.4 - 12.5 (thermal IR)	vegetation stress and soil moisture discrimination related to thermal radiation; thermal mapping (urban, water)
TM 7	2.08 - 2.35 (short wave IR)	discrimination of mineral and rock types; sensitive to vegetation moisture content

SPOT

- Earth observation imaging satellites
- Sun-synchronous, near-polar orbits at altitudes around 830 km above the Earth
- Orbit repetition every 26 days
- Equator crossing times around 10:30 AM local solar time
- First satellite to use along-track, or pushbroom scanning technology
- Twin high resolution visible (HRV) imaging systems, which can be operated independently and simultaneously.
- Each HRV is capable of sensing either in a high spatial resolution single-channel panchromatic (black-white) (PLA) mode, or a coarser spatial resolution three-channel multispectral (MLA) mode.
- Each along-track scanning HRV sensor consists of four linear arrays of detectors: one 6000 element array for the panchromatic mode recording at a spatial resolution of 10 m, and one 3000 element array for each of the three multispectral bands, recording at 20 m spatial resolution
- Swath width for both modes is 60 km at nadir

HRV Mode Spectral Ranges

Mode/Band	Wavelength Range (μm)
Panchromatic (PLA)	0.51 - 0.73 (blue-green-red)
Multispectral (MLA)	
Band 1	0.50 - 0.59 (green)
Band 2	0.61 - 0.68 (red)
Band 3	0.79 - 0.89 (near infrared)

- The viewing angle of the sensors can be adjusted to look to either side of the satellite's vertical (nadir) track, allowing off-nadir viewing which increases the satellite's revisit capability. This ability to point the sensors up to 27° from nadir, allows SPOT to view within a 950 km long swath and to revisit any location several times per week. As the sensors point away from nadir, the swath width varies from 60 to 80 km in width

- This not only improves the ability to monitor specific locations and increases the chances of obtaining cloud free scenes, but the off-nadir viewing also provides the capability of acquiring imagery for stereoscopic coverage

- By recording the same area from two different angles, the imagery can be viewed and analyzed as a three dimensional model, a technique of tremendous value for terrain interpretation, mapping, and visual terrain simulations.

Laser Fluorosensor

- Some targets fluoresce, or emit energy, upon receiving incident energy

- This is not a simple reflection of the incident radiation, but rather an absorption of the initial energy, excitation of the molecular components of the target materials, and emission of longer wavelength radiation which is then measured by the sensor

- Laser fluorosensors **illuminate the target with a specific wavelength** of radiation and are capable of detecting **multiple wavelengths of fluoresced radiation**

- Ocean applications, such as chlorophyll mapping and pollutant detection, particularly for naturally occurring and accidental oil slicks

Lidar (Laser Radar)

- Pulses of laser light are emitted from the sensor and energy reflected from a target is detected

- The time required for the energy to reach the target and return to the sensor determines the distance between the two

- Lidar is used effectively for measuring heights of features, such as forest canopy height relative to the ground surface and water depth relative to the water surface (laser profilometer)

- Lidar is also used in atmospheric studies to examine the particle content of various layers of the Earth's atmosphere and acquire air density readings and monitor air currents

5. Aircraft Scanners in the Visible and Infrared

- As with satellite image acquisition, as aircraft moves aircraft scanners provide along-track scanning while a rotating mirror or a linear detector array provides sensing data in the across-track direction

Differences between airborn and satellite-born systems:

- Data volume can be substantially higher in a airborn scanners due to

  i) Large number of spectral bands or channels available in airborne (hundreds of bands)

  ii) Large number of pixels due to high spatial resolution (< 1 m)

- FOV (Field of View is large in airborne (70 º - 90 º as compared to 10 º - 15 º in spaceborne giving rise to significant distortion in image geometry at the edges of the scan

- Stability of aircraft is poor which can lead to excessive image distortion

5.1. Thermal Infrared Multispectral Scanner (TIMS)

- Typically between 8 - 12 µm

- 6 channels

- Used to diagnose silicate rocks

5.2. Imaging Spectrometer

- Characterized by a multispectral scanner with **a very large number of channels (64-256 channels) with very narrow band widths**

- Basic scheme is almost the same as an optical mechanical scanner or pushbroom scanner.

See additional page 26

- Imaging spectrometer provides multiband imagery with a narrow wave length range

- Used for rock type classification and ocean color analysis

- Imaging spectrometers or "hyperspectral sensors" are remote sensing instruments that combine the spatial presentation of an imaging sensor with the analytical capabilities of a spectrometer.

- Up to several hundred narrow spectral bands with spectral resolution on the order of 10 nm or narrower

- Imaging Spectrometers produce a complete spectrum for every pixel of the image

See additional page 27

- Compare this to broad-band multispectral scanners such as Landsat Thematic Mapper (TM), which only has 6 spectral bands and spectral resolution on the order of 100 nm or greater.

See additional page 28

- Imaging spectrometer concept; hundreds of spectral images, thousands to millions of individual spectra

- With high spectral resolution of imaging spectrometers materials can be identified where with broad-band sensors only discrimination between materials is made.

Special Satellite Bands Used in Satellite-Ground Data Transmission:

L Band - 1.63 to 2.76 GHz
X-Band – 8.02 to 8.4 GHz downlink
Ku Band - 11.7 to 12.76 GHz Downlink
14 to 17.6 GHz Uplink
Ka Band - 18 to 31 GHz (Low Earth Orbit)
Rate of Data Transmission 150 Mbps in Landsat 7

Tracking the Satellites

- In order to record the data transmitted by the satellite, receiving antenna follows and continually points directly at the satellite. This is done as follows:

  i) Ephemeris data (tables of the predicted location of the satellite) are used to aim the antenna at the expected location (azimuth and elevation) of the satellite as it appears over the horizon

  ii) A computer moves the antenna, following along the predicted orbit of the satellite and searches for its X-band transmission

  iii) If a transmission with strong enough signal is detected then the computer will track the satellite using the X-band signal rather than the ephemeris data

Data Stream Handling at the Satellite Earth Receiving Station

See additional page 29

- The original X-band data at approximately 8GHz are received

- Data are converted to an intermediate frequency (IF) of 375 MHz by the downconverters located within the antenna structure

- The intermediate data stream are then converted (by a bit-synchronizer housed within the station building computer facility) into two different data streams:

  i) Data

  ii) Clock synchronization

- The resulting information is stored on special digital recording systems

- The digital data stream from a digital recording system is passed through a frame-synchronizer which prepares the data in "image" form

- The data is now fully compatible for conventional computer manipulation

- The digital image data are then stored on any type of computer storage medium, such as tape or compact disk

6. Microwave Image Data Sources

6.1. Radars (Radio Detection And Ranging)

- Controllable source of illumination (Active source)
- 0.3 GHz to 300 GHz (in wavelength from 1 m to 1 mm)
- Sees through cloud and rain
- Can operate day and night
- Images can be high resolution (3 - 10 m)
- Different features are portrayed or discriminated compared to visible sensors
- Following surface features can be seen better in radar images:
  - ice, ocean waves
  - soil moisture, vegetation mass
  - man-made objects, *e.g*. buildings
  - geological structures
- A Radar system has three primary functions:
  - Transmits microwave (radio) signals towards a scene
  - Receives the portion of the transmitted energy backscattered from the scene
  - Observes the strength (detection) and the time delay (ranging) of the return signals.

6.1.1. Airborne Radar

See additional page 30 (Two pages)

- Side looking Airborne Radar (SLAR)
- In SLAR, an electrical pulse in microwave frequency is radiated to the side of aircraft at an incidence angle of θ_i
- Some of this transmitted pulse energy is scattered from the ground and returned to the receiver at the aircraft
- Time delay between transmission and reflection identifies the slant distance to the target from the aircraft
- Strength of return contains information on the scattering cross-section of the target region of the Earth's surface

- Received signal from a single transmitted pulse consists of continuum of reflections from the complete region of ground that is illuminated by the radar antenna (range beamwidth of the antenna which is broad)

- Along-track (azimuth) beamwidth is chosen as small as possible so that the reflections from a single transmitted pulse can be regarded as coming to the aircraft from a narrow strip of terrain

- Forward velocity of aircraft is then arranged such that the next transmitted pulse illuminates the next strip of terrain along the swath

- Azimuth beamwidth of the antenna defines the spatial resolution in the azimuth direction (along-tract)

- Time resolution possible between echoes from two adjacent targets in the range direction (across-tract) defines the resolution in the slant direction

- Concerning the image, slant range resolution is not of interest, but ground range resolution (projection of slant range resolution onto the horizontal plane) is to be considered

- r_g = ground range size of a resolution element (pixel) = $c \tau / (2 \sin \theta_i)$ where τ is the pulse length, θ_i is the incidence angle

- As θ_i ↗ , r_g ↘ , i.e resolution gets better, i.e better ground range resolution on the far side of the swath

- r_a =azimuth size of the resolution element is related to the length (or aperture) of the transmitting antenna in the azimuth direction, d as $r_a = R_0 \lambda / d$ where R_0 is the range between the aircraft and target

- As length (or aperture) of the transmitting antenna in the azimuth direction = d ↗ r_a ↘ , i.e resolution gets better. This is the starting point for SAR (Synthetic Aperture Radar)

6.1.2. Synthetic Aperture Radar (SAR)

Concept of Synthetic Aperture

See additional page 31(Two pages)

- A side-looking radar system which makes a high-resolution image of the Earth's surface (for remote sensing applications)

- Continuous strips of the ground surface are "illuminated" parallel and to one side of the flight direction.

- The **across-track dimension** is referred to as "**range**". Near range edge is closest to nadir (the points directly below the radar) and far range edge is farthest from the radar.

- The **along-track dimension** is referred to as "**azimuth**"

- In a radar system, resolution is defined for both the range and azimuth directions

- Higher resolution than achieved by conventional radar

- Measurement and resolution are achieved in synthetic aperture radar in the same manner as most other radars: Range is determined by precisely measuring the time from transmission of a pulse to receiving the echo from a target and, in the simplest SAR, range resolution is determined by the transmitted pulse width, i.e. narrow pulses yield fine range resolution

- **It is the ability of SAR to produce relatively fine azimuth resolution that differentiates it from other radars.**

- To obtain fine azimuth resolution, a physically large antenna is needed to focus the transmitted and received energy into a sharp beam

- The sharpness of the beam defines the azimuth resolution

- Since SARs are operating in microwave fine SAR resolutions require an antenna physically larger than can be practically carried by an airborne platform: antenna lengths several hundred meters long are often required

- However, an airborne radar could collect data while flying this distance and then process the data as if it came from a physically long antenna

- The distance the aircraft flies in synthesizing the antenna is known as the synthetic aperture

- A narrow synthetic beamwidth results from the relatively long synthetic aperture, which yields finer resolution than is possible from a smaller physical antenna

- Achieving fine azimuth resolution may also be described from a doppler processing viewpoint:

    - A target's position along the flight path determines the doppler frequency of its echoes

    - Targets ahead of the aircraft produce a positive doppler offset

    - Targets behind the aircraft produce a negative offset

    - As the aircraft flies a distance (the synthetic aperture), echoes are resolved into a number of doppler frequencies

    - The target's doppler frequency determines its azimuth position

Sensor resolution of SAR

See additional page 32(Two pages)

- Resolution of a SAR sensor is different than pixel spacing which results from sampling done by the SAR image processor.

- **Sensor resolution** has two dimensions (i.e yields 2-D image):

i) Range resolution

- Range resolution depends on the length of the processed pulse
- Shorter pulses result in "higher" resolution
- Radar data are created in the slant range domain, but usually are projected onto the ground range plane when processed into an image.

ii) Azimuth resolution

- Real aperture radar has azimuth resolution determined by the angular beam width of the terrain strip illuminated by the radar beam
- For two objects to be resolved, they must be separated in the azimuth direction by a distance greater than the beam width on the ground
- A synthetic aperture radar (SAR) the azimuth resolution to much shorter
- than the antenna length
- SAR gets its name from the azimuth processing and using signal processing to refine azimuth resolution, it can achieve an azimuth resolution which may be hundreds of times smaller than the transmitted antenna beam width

Microwave Radar Operating Frequencies

- Most remote sensing radars operate at wavelengths between .5 cm to 75 cm
- Microwave frequencies are arbitrarily assigned to bands identified by letter

BAND	WAVELENGTH	FREQUENCY	APPLICATION	VEHICLE USED
X-band	2.4 to 3.75 cm	12.5 to 8 GHz	Military reconnaissance and commercially for terrain surveys	CV-580 SAR (Environment Canada)
C-band	3.75 to 7.5 cm	8 to 4 GHz		Spaceborne SARs, such as ERS-1 and RADARSAT
S-band	7.5 to 15 cm	4 to 2 GHz		Almaz
L-band	15 to 30 cm	2 to 1 GHz		SEASAT and JERS-1
P-band	30 to 100 cm	1 to 0.3 GHz		NASA/JPL AIRSAR

- The capability to penetrate through precipitation or into a surface layer is increased with longer wavelengths
- Radars operating at wavelengths greater than 2 cm are not significantly affected by cloud cover
- However, rain does become a factor at wavelengths shorter than 4 cm

Choice of Radar Frequency

Application factors**:**

– Radar wavelength should be matched to the size of the surface features that we wish to discriminate

  – *e.g.* Ice discrimination, small features, use X-band

  – *e.g.* Geology mapping, large features, use L-band

  – *e.g.* Foliage (bitki, yeşillik) penetration, better at low frequencies, use P-band

- In general, C-band is a good compromise

System factors:

– Low frequencies:

  - More difficult processing

  - Need larger antennas and feeds

  - Simpler electronics

– High frequencies:

  - Need more power

  - More difficult electronics

  - Good component availability at X-band

- Note that many research SARs have multiple frequency bands

  – *e.g.* JPL AIRSAR, SIR-C, Convair-580

Polarization

See additional page 33

- Polarization is the orientation of the electric vector of an electromagnetic wave.

- Radar system antennas can be configured to transmit and receive either horizontally or vertically polarized electromagnetic radiation

- When polarization of the transmitted and received waves is in the same direction, it is referred to as like-polarized

- HH refers to horizontally transmitted and received waves

- VV refers to vertically transmitted and received waves

- When polarization of the transmitted waves is orthogonal to the polarization of the received radiation, it is referred to as cross-polarized; *e.g.* HV refers to horizontal transmission and vertical reception; VH for vertical transmission and horizontal reception

- When the radar wave interacts with a surface and is scattered from it, the polarization can be modified, depending upon the properties of the surface. This modification affects the way the scene appears in polarimetric radar imagery, and the type of surface can often be deduced from the image

Choice of Polarization

- Basic or operational SARs usually have only one polarization for economy, *e.g.* HH or V V

- Research systems tend to have multiple polarizations, *e.g.* all of HH, HV, V V, VH (quad pol)

- Multiple polarizations help to distinguish the physical structure of the scattering surfaces:

  – Alignment with respect to the radar (HH *vs.* V V)

  – Randomness of scattering (*e.g.* vegetation - HV)

  – Corner structures (*e.g.* HH V V phase angle)

  – Bragg scattering (*e.g.* oceans – V V)

Radar shadows in imagery

See additional page 34

- Areas on the ground surface not illuminated by the radar

- Since no return signal is received, radar shadows appear very dark in tone on the imagery

- Information about the scene, such as an object's height, can also be obtained from radar shadows.

Fading and speckle

See additional page 35

- Noise-like processes which degrade image quality in a coherent imaging system.

- Fading is due to variation in the echo phase delay caused by multiple targets in a resolution cell with range variations differing by less than a wavelength.

- Local constructive and destructive interference appears in the image as bright and dark speckles, respectively

- Using independent data sets to estimate the same ground patch, by average independent samples, can effectively reduce the effects of fading and speckle

Surface roughness

See additional page 36

- Influences the reflectivity of microwave energy and thus the brightness of features on the radar imagery

- Horizontal smooth surfaces reflect nearly all incident energy away from the radar and are called specular (meaning mirror) reflection

- Specular surfaces, such as calm water or paved highways, appear dark on radar imagery

- Microwaves incident upon a rough surface are scattered in many directions. This is known as diffuse or distributed reflectance

See additional page 37

- Vegetation surfaces will cause diffuse reflectance and result in a brighter tone on the radar imagery.

- In general, scenes observed by a SAR consist of two kinds of reflecting surfaces; distributed scatterers and discrete scatterers

- **Discrete scatterers** are characterized by a relatively simple geometric shape, such as a building. The classic element used to represent discrete scattering is a corner reflector, a shape as is formed when all sides intersect at (nearly) right angles such as the intersection of a paved road and tall building

- **Distributed scatterers** consist of multiple small areas or surfaces from which the incident microwaves scatter in many different directions. Distributed scattering is produced from a forest canopy or cultivated fields.

- Radar measures that component of the scattered energy which returns along the same path as the incident beam.

- Surface roughness of a scattering surface is determined relative to radar wavelength and incident angle

- A surface is considered smooth if surface height variations $<< \lambda$

- In terms of a single wavelength, a given surface appears rougher as incident angle increases

- Rough surfaces will usually appear brighter on radar imagery than smoother surfaces composed of the same material

- Rough surface can be defined as having a height variation of about half the radar wavelength

Corner Reflectors

See additional page 38

- Small objects may appear extremely bright on radar imagery. This is dependent on the geometric configuration of the object
- The side of a building or a bridge, combined with reflection from the ground is an example of a corner reflector
- When two surfaces are at right angles and open to the radar, a dihedral corner reflector is formed. The return from a dihedral corner reflector is strong only when the reflecting surfaces are very nearly perpendicular to the illumination direction
- Strong reflections are caused by a trihedral corner reflector. These are formed by the intersection of three mutually perpendicular plane surfaces open to the radar
- Researchers often place corner reflectors at various ground locations to act as reference points on the radar imagery

Volume scattering

See additional page 39

- Related to multiple scattering processes within a medium, such as the vegetation canopy of a corn field or a forest
- Multiple scattering can also occur in layers of very dry soil, sand, or ice
- Important as it influences the backscatter observed by the radar
- Radar will receive backscatter from both the surface and the volume
- The intensity of volume scattering depends on:

  i) The physical properties of the volume variations especially in the dielectric constant

  ii) Characteristics of the radar (wavelength, polarization and incident angle)

- The presence of moisture increases a material's complex dielectric constant
- The dielectric constant influences the ability of a material to absorb, reflect and transmit microwave energy.
- The moisture content of a material can change its electrical properties. This affects how a material appears on the radar image
- Identical materials can vary in appearance at different times or different locations according to the amount of moisture they contain
- The reflectivity, and hence image brightness, of most natural vegetation and surfaces is increased with increasing moisture content

- Microwaves may penetrate very dry materials, such as desert sand. The scattering which results, is affected by both surface and subsurface properties

- In general, the longer the radar wavelength, the deeper into the material the energy will penetrate.

Advantages of satellite SARs (RADARSAT)

– More coverage per second (Km^2/s)
– Lower operating costs ($\$/Km^2$)
– Not constrained by flying conditions or airport proximity
– Wider area views
– Somewhat simpler signal processing (no motion compensation)

Disadvantages of satellite SARs (RADARSAT)
– More expensive to design, build and launch
– More difficult to provide multiple polarizations & frequencies
– Cannot be flown anywhere on demand
– Lower resolution in general

Imaging Modes of RADARSAT-1

See additional page 40 (Two pages)

Comparison of Imaging Geometries of Spaceborne SAR and Airborne SAR

See additional page 41

7. Geospatial Data and GIS (Geographical Information Systems)

GIS is a "computer system for capturing, managing, integrating, manipulating, analysing and displaying data which is spatially referenced to the Earth.

GIS differs from other forms of information systems (like databases and spreadsheets) since GIS deals with spatial information.

GIS has the capability to relate layers of data for the same points in space, combining, analysing and, finally, mapping out the results.

Spatial information uses location, within a coordinate system, as its reference base.

The most common representation of spatial information is a map on which the location of any point could be given using latitude and longitude.

Major areas of application of GIS

- Different streams of planning

- Urban planning, housing, transportation planning, architectural conservation, urban design, landscape

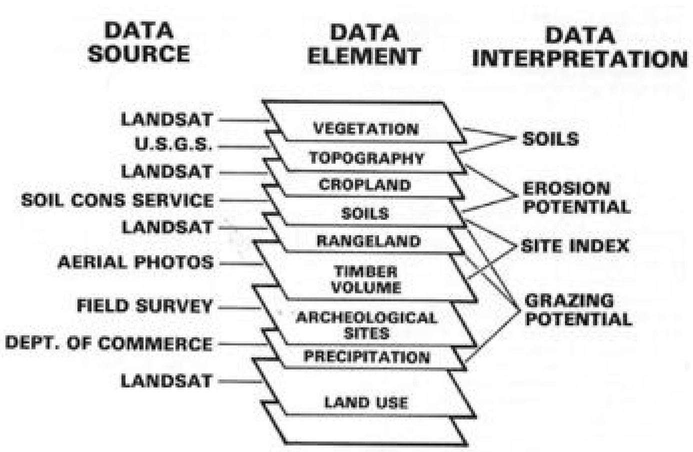
- Street network based application
- Vehicle routing and scheduling: location and site selection and disaster planning
- Natural Resource Based Applications like management and environmental impact analysis of wild and scenic recreational resources, flood plain, wetlands, forests and wildlife
- Hazardous or toxic factories siting and ground water modelling
- Wild life habitat study and migrational route planning
- Land parcel based zoning, sub-division plans review, land acquisition, environment impact analysis, nature quality management and maintenance
- Facilities Management
- Locating underground pipes and cables for maintenance, planning, tracking energy use
- Tool for crime analysts in many police departments

One of the advantages of GIS is its ability to integrate information from a variety of sources into one user interface which allows for spatial analyses that would either not have been possible or very difficult prior to the advent of GIS.

- Water supply companies use GIS as a spatial database of pipes and manholes
- Municipalities can use GIS to manage and update property boundaries, emergency operations and environmental resources
- GIS can be used to map out the provision of services, such as health care and primary education, taking into account population distribution
- GIS is being used to assist businesses in identifying their potential markets and maintaining a spatial database of their customers

* GIS data are usually stored in more than one layer in order to overcome the technical problems caused by handling very large amounts of information at once
* It is easier to work with complex spatial problems one layer at a time
* Working with layers of geographical information is known as data integration and this is a fundamental aspect of GIS
* For example, GIS of a region may consist of several layers of data:
    - Layer 1: Property boundaries and land use types (as area maps)
    - Layer 2: Road and railway networks (as line maps)
    - Layer 3: Terrain characteristics (as spot-height or contour maps)
    - Layer 4: Hospital, school ..etc. locations (as point maps)

- Spatial data is represented in one (or both) of the two following formats:
  - Vector model, as geometric objects like points, lines, polygons
  - Raster model, as image files composed of pixels
- Data Elements and Models
  - The interrelations among variables are usually very complex
  - **GIS Example:** To control the crop production process, a model is formulated for the crop growth that accounts for the dynamic interactions and cause-effect responses of the appropriate factors
  - Model establishes the functions, sequences, and feedback effects of the determining variables



(Otlatma Potansiyeli)

  - In the above diagram, information is taken from:
    - i) Various conventional sources
    - ii) Data from Landsat or similar Earth-observing satellites
  - Information is combined to produce data elements
  - From data elements interpretation maps and other output types are produced
  - These outputs become parts of environmental resource planning, site selection, and other desired applications
  - Interpretative maps are derivatives (i.e., they result from decisions to produce new object categories, originating from combinations of several others)
  - E.g: A map may contain the likelihood of erosion, which can deduced from maps showing:

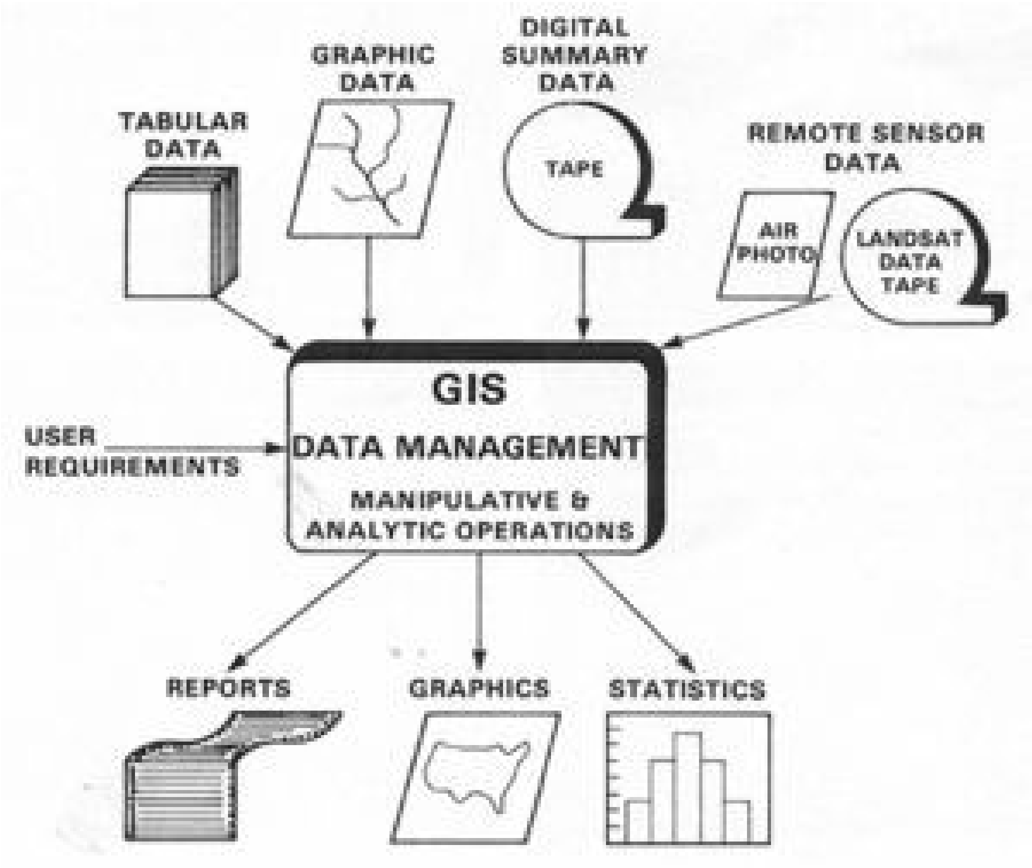
i) Soil properties

ii) Topography

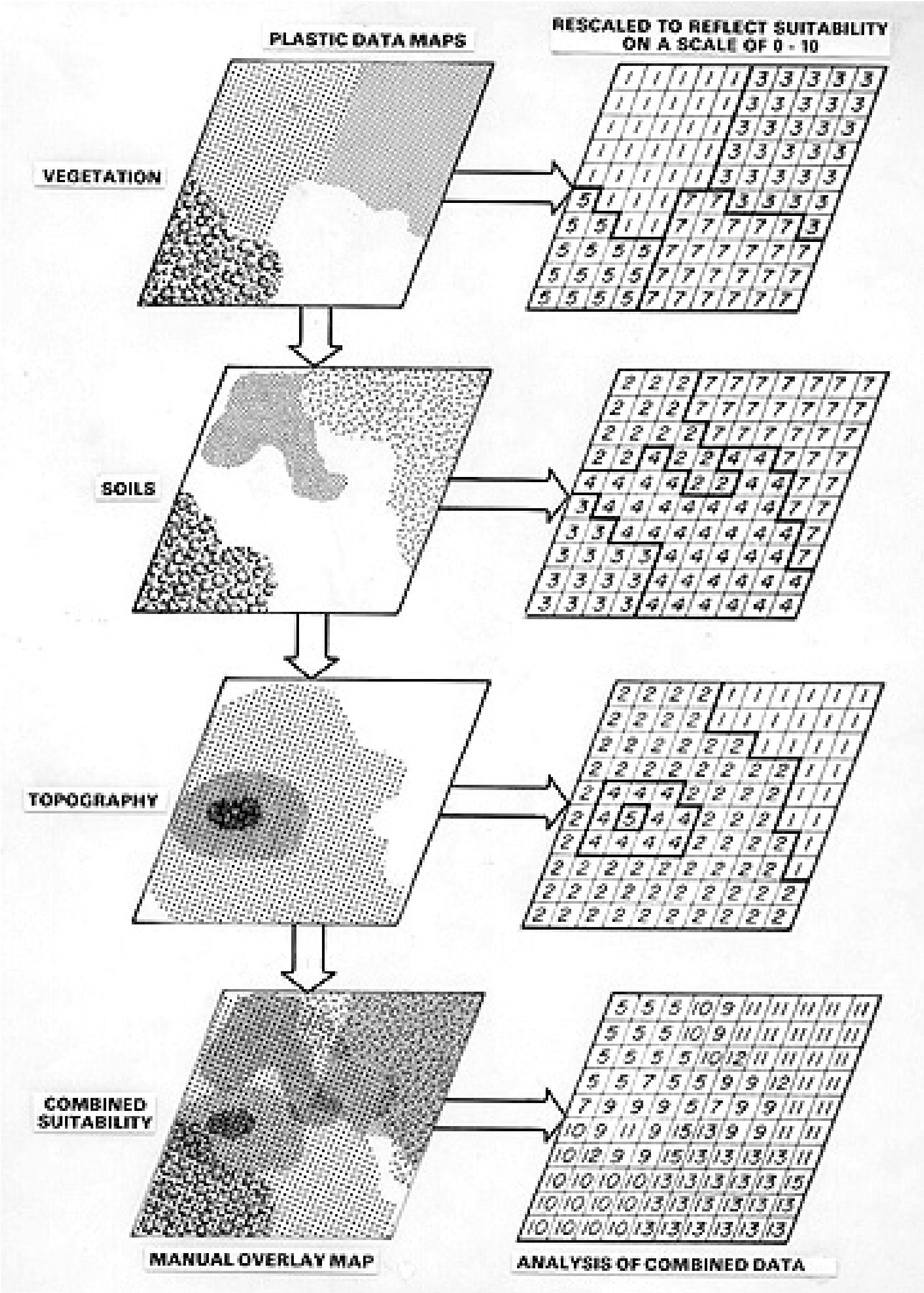
iii) Rainfall

iv) Stream patterns

v) Other related factors



- **GIS Case Study - 1** and the thinking behind the steps in a site-suitability analysis



- Suppose that three factors or variables, among the attributes that describe a geographic area under consideration, are essential in determining best sites for a land development venture:

  i) Vegetation

  ii) Soils

  iii) Topography

- A data element on a map represents each variable

- In this case the map shows the characteristics and distribution of the members or classes within the element theme, e.g., different types of soils and their properties

- Usually one map, often a cartographic map (maps representing spatial distributions over various areas of the earth) is designated as the base, over which the other maps are laid

- Each map then constitutes a data layer either manually or digitally

- Some soils, vegetation cover types, and elevations are more favorable than others in specifying their role in the site-selection process

- Thus, for a certain intended use, we prefer high areas over low areas

- So, numerical ratings, say from 1 to 5 are assigned to relative heights

- Soils with optimum drainage can be marked by higher numbers in a scale of 1 to 8

- Then a data element map is subdivided into pixels

- Each cell is assigned a value based on its thematic rating

- Other kinds of data can be incorporated, e.g., tables representing some condition in the pixels, provided there is some spatial connection

- When the maps sharing the same pixels are combined, each comprising a data layer, the values of **sum** for each pixel, ranging from:

  (lowest numbers = worst suited) to (highest = best suited)

- In GIS, this is usually done digitally

- The outcome is a map, in which the areas with the highest resultant scores are judged the most favorably suited

• The numerical data and their values need to be assigned to each cell. This is called encoding

GIS Case Study - 2

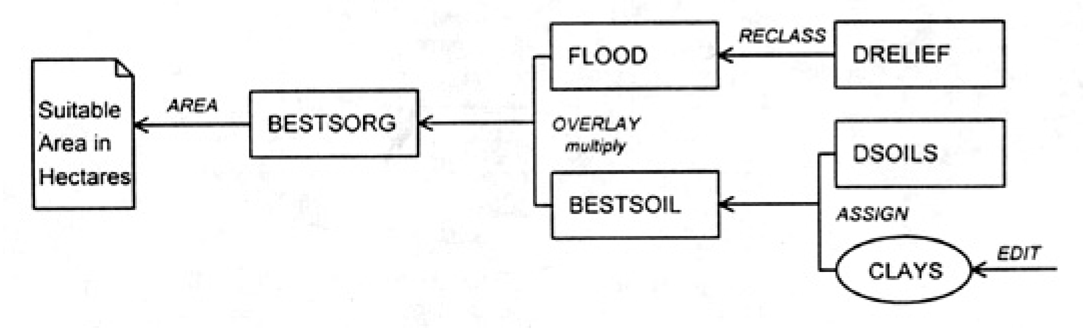
- Simplified example contains only a few of the many data elements that is normally considered in the model

- In order to easily manipulate the data, ranking mode within each element is reduced to acceptable (1) or not-acceptable (0)

- The problem is identifying the best areas for planting a cereal crop (sorghum) within a valley along a River

- Among the many applicable agricultural factors, here only the key factors, such as, soil types, relief (range of elevations) and periodic flooding (which promotes sorghum growth) are considered

- Below flow chart outlines the sequence of steps for using GIS to automate the decision about suitable areas for sorghum planting:



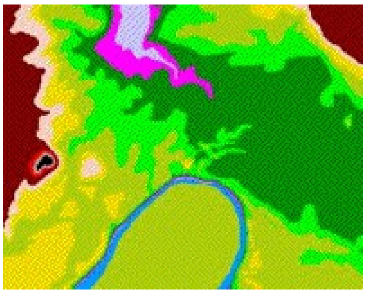
- In this flow chart, annotations are from the IDRISI software program used for GIS applications

- The first factor is the elevation variations or relief

- Field surveys have led to a digital elevation model (DEM) data set

- From DEM data set, general topographic map image with 3-meter contour interval (file name DRELIEF) is produced

RELIEF (ELEVATION) IMAGE



- The sequence of increasing elevations, as color-coded is: blue (lowest, associated with the river), medium gray, purple-red, dark green, medium green, olive, yellow, tan, brown, red, darker gray and black
- The relief or range of elevations is 33 m

- Gentle hills occur in the west and northeast sections

- Lowlands extends across the river

- An unusual lower area (a gully, i.e. a flood bed) is present in the north center of the image

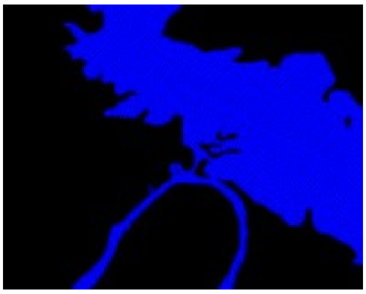
- This depression controls the location and retention of water (keeping water) during floods that take place routinely during the rainy season

- Flood stages can reach 9 m above the normal stream level

- Using this elevation range of 9 m as a constraint, RECLASS routine of IDRISI is used

- RECLASS routine gives boolean algebra values of 0 and 1 to produce the below image (named FLOOD) that defines the area of flooding (in blue)

FLOOD IMAGE



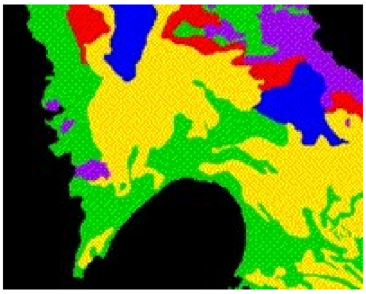
- In the above FLOOD image, 1 is assigned to all elevation values (in blue) less than 9m, i.e., region having tendency for flooding, and 0 to all values above this level (black in the image)

- Soil types in the region differentially absorb floodwaters; some retain enough over the long term to provide a continuing supply of moisture during the growing season

- Thus, soil type is another critical factor

- Below is a map (DSOILS) of the distribution of five soils within the region:

SOIL IMAGE

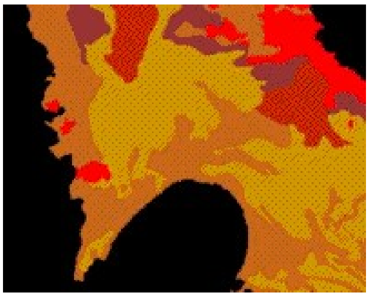


- In the above Soil Image; blue = heavy soils (1), yellow = clays (2), red = sandy clays (3), green = levee soils (4), purple = stony soils (5)

- IDRISI software allows to give each soil a suitability ranking, as follows: best (5) = clays, then in decreasing quality, levee soils (4), sandy clays (3), heavy clays (2) and worst, stony soils (1). The black areas are not considered further

- Then, a map (SORGSUIT) is produced in which the soils are rated by suitability, using the IDRISI ASSIGN program

SORGSUIT (SORGHUM CROP SUITABILITY) MAP



- In this map, red = 1 (least suitable); brown = 2; dark brown = 3; light brown = 4, yellow = 5 (most suitable); black (not considered)

- Above Sorgsuit map has the same distribution pattern as the soils image above, but now, the computer is instructed to give each soil a numerical value

- This numerical value is an attribute that represents its productiveness for growing this crop), instead of a soil-type name

- Next step is to generate a map that shows the location and sizes of patches of clay soil (in green) that constitute the best soil (named BESTSOIL) for growth

BEST SOIL IMAGE

- Final step in the flow chart is to combine the information in the FLOOD and BESTSOIL maps as an OVERLAY to generate a decision end product map, called BESTSORG

- Again, Boolean algebra is used

- On each of the intermediate maps (FLOOD and BESTSOIL), there are just two themes or patterns, one in color and the other in black, representing the idea of "good" or "appropriate" (flooded, optimum soil) and "not suitable" respectively

- Let "acceptable" = 1 and "not suitable" = 0

- Each data cell (the grid is implicit in the above maps but is not shown) for each map then has either a 1 or a 0 within it

- Since the two intermediate maps are at the same scale and projection, they fit or register in the overlay process

- An analog process can be used, i.e., transparencies of the two maps are made and visually overlay them on a lighted table

- Te same result can also be produced digitally, by combining data in the grid cells for each map

- Following this map-algebra operation:

FLOOD		BESTSOIL	BESTSORG
0	X	0	0
0	X	1	0
1	X	0	0
1	X	1	1

- Thus, only those cells that are colored (1) in both maps make a product score of 1

- These form continuous patches, colored red, in the BESTSORG map produced by OVERLAY shown below:

BESTSORG MAP

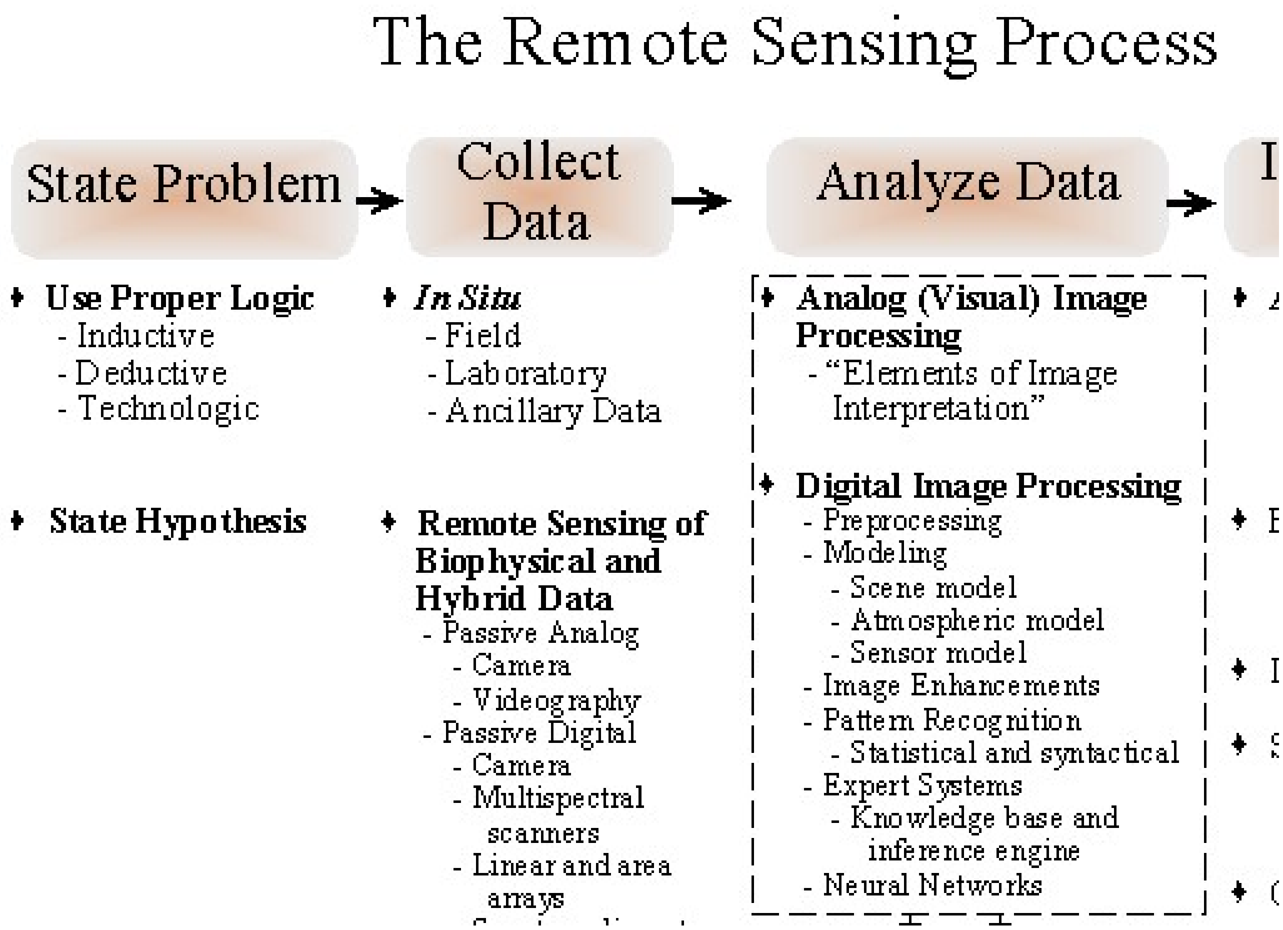
- Since the area of each pixel is known, the total area associated with suitable conditions is just the product of the number of pixels times the unit area. In IDRISI, the two programs GROUP and AREA do this

- Many other attributes and thematic factors in a real suitability case can be included like access (roads, etc.), Market Requirements, Fertilizer Needs, Manpower Availability, etc.

- Some of these factors can be expressed as maps and others as data that we may organize into value tables. These data can be integrated in GIS models that add to the scores in each pixel

- Also as shown in the Site Suitability illustration above, one could apply a different system of ranking, in which a range of rankings can be associated, say, from 1 to 10 (rather than just 0s and 1s), with each pixel, and then sum them for all the data elements.

7.3. Image Processing and Analysis



- Remotely sensed data is analyzed using various image processing techniques and methods including both of the

  i) Visual (or analog) processing techniques applied to hard copy data such as photographs or printouts

  ii) Application of digital image processing algorithms to the digital data

- One of the purposes of applying both analog and digital techniques to remotely sensed data is to enable the analyst see the data in several ways

- The goal of image processing is to allow the researcher to examine their data from all possible angles, to place entire images in context with their surroundings and to allow the relationships of individual scene elements to be discovered

Analog Image Processing

- Scientific visualization is the process of exploring data visually to gain an intimate knowledge and insight about the data

- Elements of Image Interpretation:

  - **Shape** – Outlines of objects (e.g. Specific building)

- **Size** – In context of image scale (e.g. Houses / Industrial buildings)
- **Pattern** – Spatial arrangement of objects (e.g. trees in an orchard (fruit garden) versus forest tree stands)
- **Tone** – Relative brightness or colour of objects (e.g. Light toned and Dark toned soils, Deciduous Trees which lose their leaves inwinter versus Coniferous Trees which do not lose their leaves in winter)
- **Texture** – Smoothness or Coarseness of image features (green grass vs. green tree)
- **Shadows** – E.g. Shadows of Trees bridges help in their identification
- **Site** – Geographic location (e.g. Crops in well-drained vs. poorly drained sites)
- **Association** – Context of occurrence (e.g. Barn in an agricultural area)

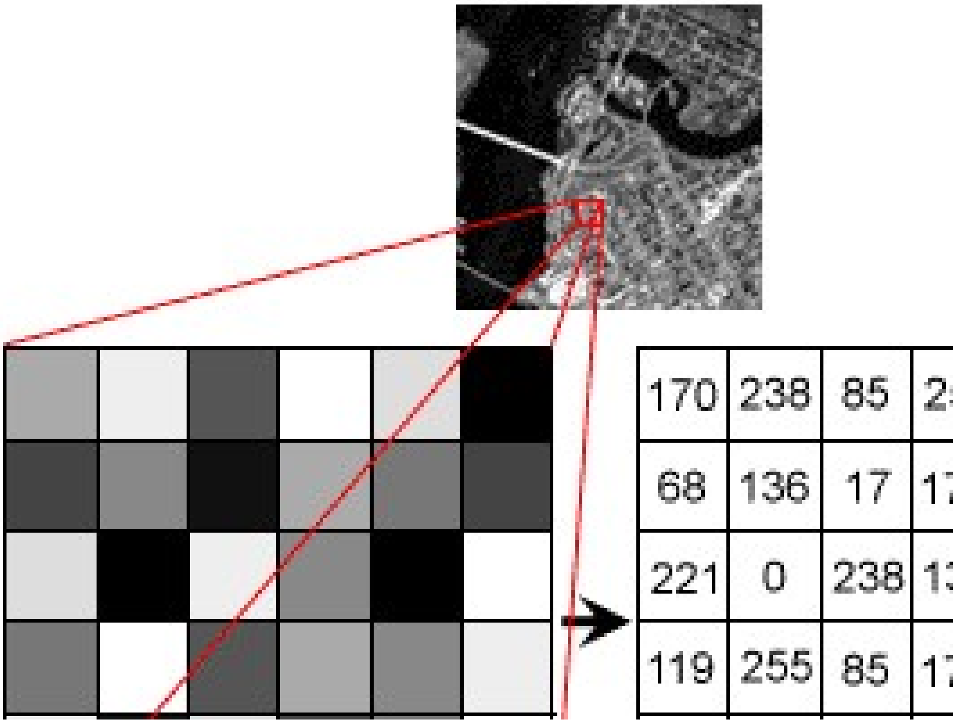
- Everyone continually processes images in daily life
- As you walk down the street you see cars, other people, take note of the weather, etc.
- All these images are passed to our brain where all of our experiences and learning are used to extract the most pertinent information
- Similarly, you apply collateral data and personal knowledge to the task of image processing
- This, combined with the multi-concept of examining remotely sensed data:
  - In multiple bands of the electromagnetic spectrum (multispectral)
  - On multiple dates (multitemporal)
  - At multiple scales (multiscale)
  - In conjunction with other scientists (multidisciplinary),
- Eventually a judgement is made what the object is and its significance

- Other tasks performed in analog image processing include Optical Photogrammetric techniques allowing for precise measurement of height, width, location, etc. of an object

Digital Image Processing

- The ultimate goal of digital image processing is to extract information from an image that is not readily apparent or is not available in its original form
- Image is in digital format
- Image is composed of pixels representing digital numbers for brightness (e.g. from 0 (representing black) to 255 (representing white) in an 8 bit radiance resolution)

• Because of digital pixel structure, remote sensing inputs fit well into Raster GIS models.



Digital Image Processing Functions

1) Image Preprocessing

- Concerned with removal of errors in Data – sensor and platform related
- Correction for velocity, altitude and earth curvature (carried out at ground receiving stations)
- Radiometric pre-processing (for missing scan lines, de-striping)
- Geometric corrections (for geo-referencing)
- Radiometric corrections (using multi-temporal images)
- Atmospheric corrections (haze removal)

2) Image Enhancement

- Usually done to more effectively display or record the data for subsequent visual interpretation.
- Contrast stretching
- Filtering

- Edge enhancement

3) Image Transformations

- Arithmetic operations done to combine and transform the original bands into "new" images which better display or highlight certain features in the scene

4) Image Classification and Analysis

- To categorize all pixels in an image into land cover classes or themes
- Multi-spectral data are used to perform classification
- Spectral patterns present within data used as numerical basis for categorization

Comparison of Analog (Visual) and Digital Image Processing

Analog (Visual) Image Processing	Digital Image Processing
• Uses all available elements	• Relies mainly on the tone and color of image pixels
• Traditional: intuitive	• Recent: requires specialized training
• Simple, inexpensive equipment	• Complex, expensive equipment
• Uses brightness (limited grey levels) and Spatial content of the image	• Relies chiefly upon brightness and spectral content (detection of subtle spectral differences) , limited spatial
• Usually single channel data or three channels at most	• Frequent use of data from several channels.
• Subjective, concrete, qualitative	• Objective, abstract, quantitative

- Digital image processing is also applied with expert systems and neural networks which attempt to enable the computer to mimic the ways in which humans interpret images
- **Expert systems** accomplish this through the compilation of a large database of human knowledge gained from analog image interpretation which the computer draws upon in its interpretations
- **Nueral networks** attempt to 'teach' the computer what decisions to make based upon a training data set. Once it has 'learned' how to classify the training data succesfully, it is used to interpret and classify new data sets.

Information Output of Image Processed Data

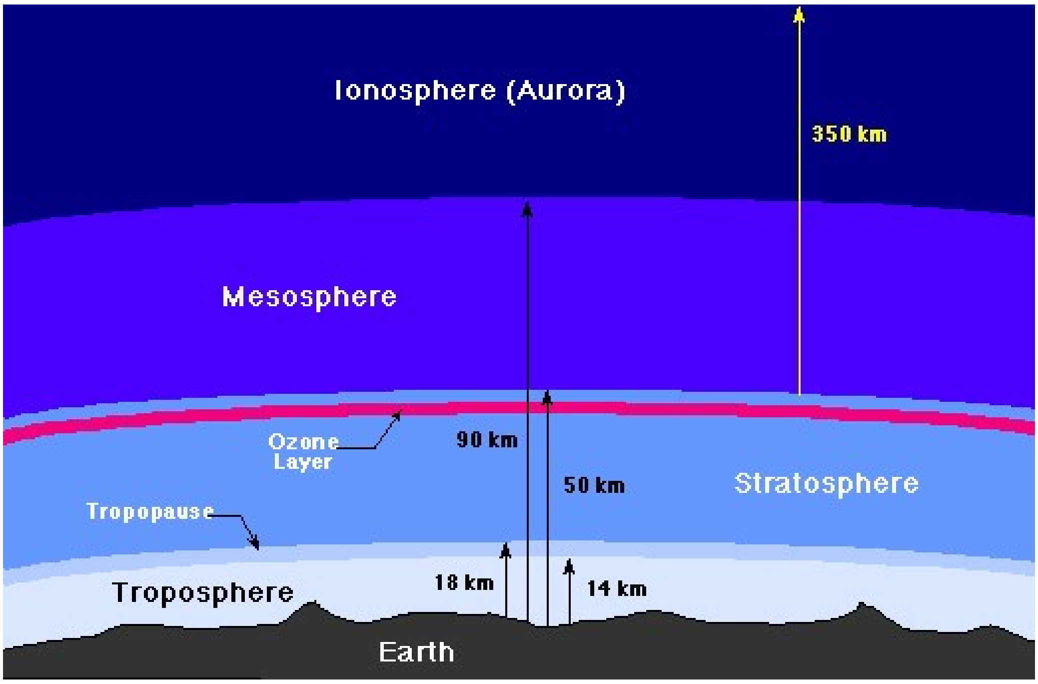
- After the remotely sensed data is processed, it must be placed into a format that can effectively transmit the information it was intended to. This can be done in a variety of ways including:

    - Printout of the enhanced image itself
    - Image map
    - Thematic map
    - Spatial database
    - Summary statistics and/or graphs

9. Error Correction and Registration of Image Data

Atmospheric, Geometric, Radiometric Distortion and Correction

ATMOSPHERE



CONTENT AND BASIC PROPERTIES OF THE ATMOSPHERE

Composition of the Atmosphere

- Composition of the atmosphere is important to understand the role which the atmosphere plays in remote sensing and in interactions with electromagnetic radiation

- Atmosphere is to a large extent a mixture of gases, some with fairly constant concentrations, others that are variable in space and time

- Additionally there are suspended particles (e.g. aerosol, smoke, ash etc.) and hydrometeors (e.g. cloud droplets, raindrops, snow, ice crystals, etc)

- About 99% of the mass lies below an altitude of 30km. Table 1 below shows the composition of the atmosphere below 100km.

Constituent	% by volume	Variable constituents	
Nitrogen (N_2)	78.08	Water vapour	0
Oxygen (O_2)	20.95	Ozone	0
Argon (Ar)	0.93	Ammonia (NH_3)	0
Carbon dioxide (CO_2)	0.033	Sulphur dioxide (SO_2)*	0
Neon (Ne)	18.2 x 10^-4	Nitrogen dioxide (NO_2)*	0
Helium (He)	5.2 x 10^-4	other gases	t
Krypton (Kr)	1.1 x 10^-4	aerosols, dust, gases	h
Xenon (Xe)	0.089 x 10^-4		
Hydrogen (H_2)	0.5 x 10^-4		
[illegible]	[illegible]		

- Above table shows the main constituents of the earth's atmosphere (* denotes concentration near the earth's surface)

- Nitrogen, oxygen and argon account for about 99.99% of the permanent gases

- Carbon dioxide can be variable in concentration on a localised basis at low levels

- Water vapour content may vary from about 0 to 4%

- Ozone concentrations also vary

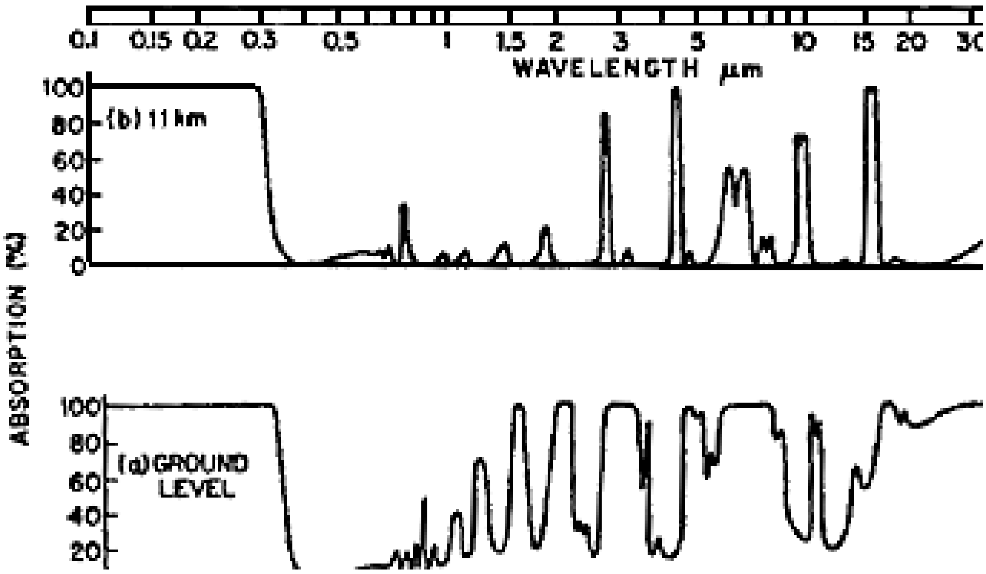
- In addition to these variable constituents there are also aerosols and hydrometeors which can vary widely in space and time

- Atmospheric gases critically affect the earth's global energy balance through absorption and re-emission

- Solar radiation reaching the earth's surface is determined by atmospheric gases

- E.g. harmful UV radiation is blocked by the ozone layer

- Below figure shows atmospheric absorption for solar radiation for the layer of atmosphere above 11km and at the ground level



Absorber	Symbol	Spectral Re
Carbon dioxide	CO_2	13.5-16.5 um (center a
		4.2-4.4 um (center at 4
		10.4, 9.4, 5.2, 2.7, 2.0
		1.4 um; also a series of
		in the 0.78-1.24 um ra
Molecular oxygen	O_2	1.07 and 1.27 um, a ser
		between 50-70 GHz, on
		118.75 GHz; also weak b
		visible, with centres be
		5384 and 7621Å
Water vapour	H_2O	5.5-7.5 um (centre at 6
		2.6-3.3 um (several ce
		1.4, 1.1, 0.94, 0.81, 0
		22.24 and 183.31 GHz,
		at frequencies higher tha
		that extend all the way t
		a few weak bands in the
Ozone	O_3	14.1, 9.6, 9.0, 5.75, 4.
		3.27, 2.7um, 18 lines be
		and 43.65 GHz, lines at
		101.74 and 118.36GHz,
		lines between 160 and 3
		1800-3400 A (centre a
		3200-3600 A, 4400-7
Methane	CH_4	3.3 and 7.7 um
Nitrous oxide	N_2O	4.5, 7.8, 17.0 um, plus
		50, 25 GHz

- Above table gives the main atmospheric gases which absorb radiation along with their absorbing regions, at ultraviolet (UV), visible, infrared (IR) and microwave wavelengths

- Also, the main spectral regions for which atmospheric absorption is small **("windows)** allow ground-based measurements of celestial objects, and satellite-based measurements of the earth's surface or clouds for remote sensing applications. Windows are indicated in the above table

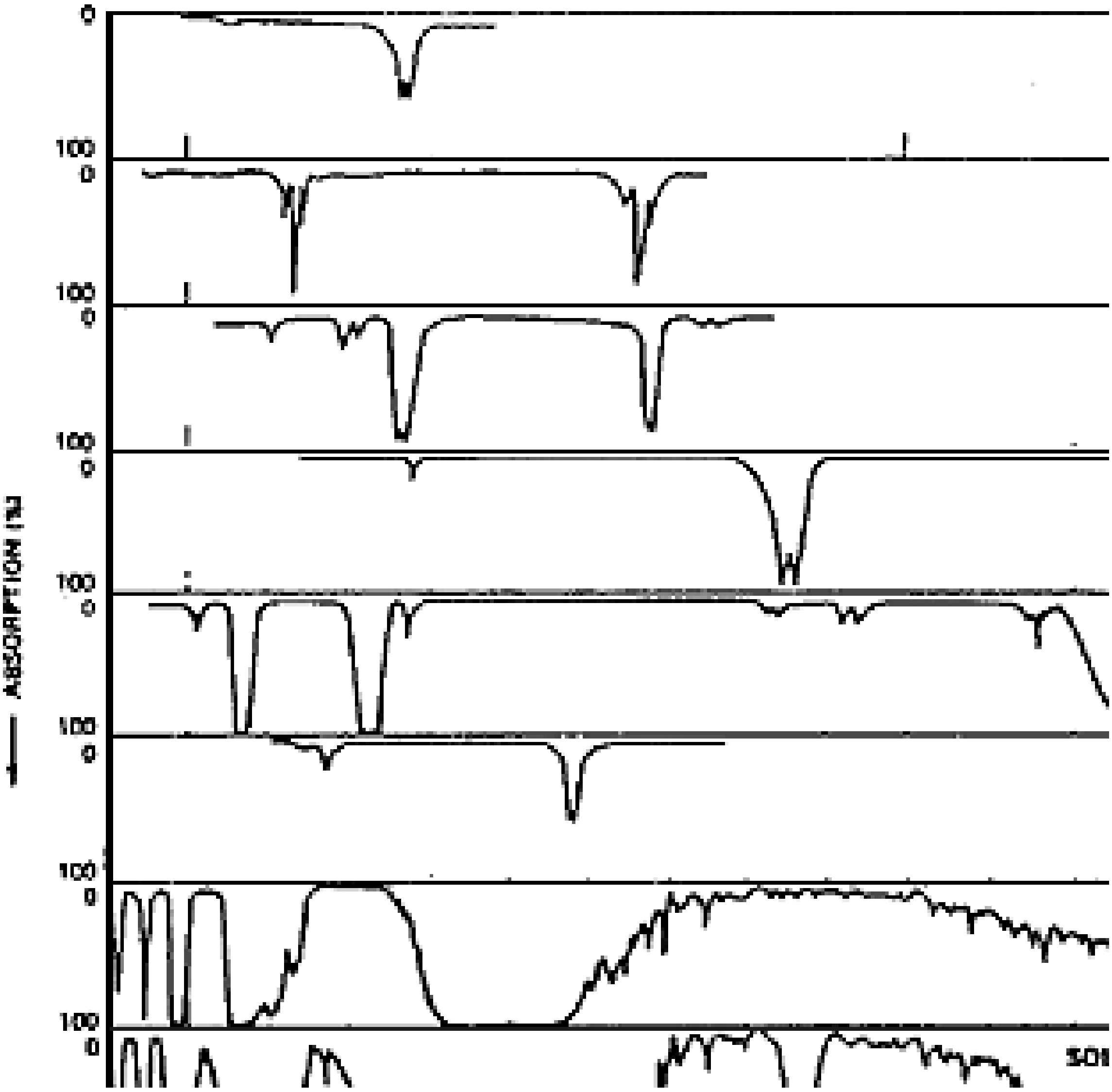
- Atmosphere is relatively transparent from about 8 to 13 microns. This region is referred to is an atmospheric window and is commonly used by IR imaging sensors on meteorological satellites

- In a clear atmosphere without clouds and aerosols, a large portion (about 50%) of solar energy transmits through the atmosphere and is absorbed by the earth's surface

- Energy emitted from the earth, on the contrary, is absorbed largely by carbon dioxide, water vapour, and ozone in the atmosphere

- Trapping of thermal infrared radiation by atmospheric gases is called the greenhouse or atmospheric effect

- Atmospheric absorptivity as a function of wavelength is shown in the below Figure for visible and IR wavelengths for separate gases.

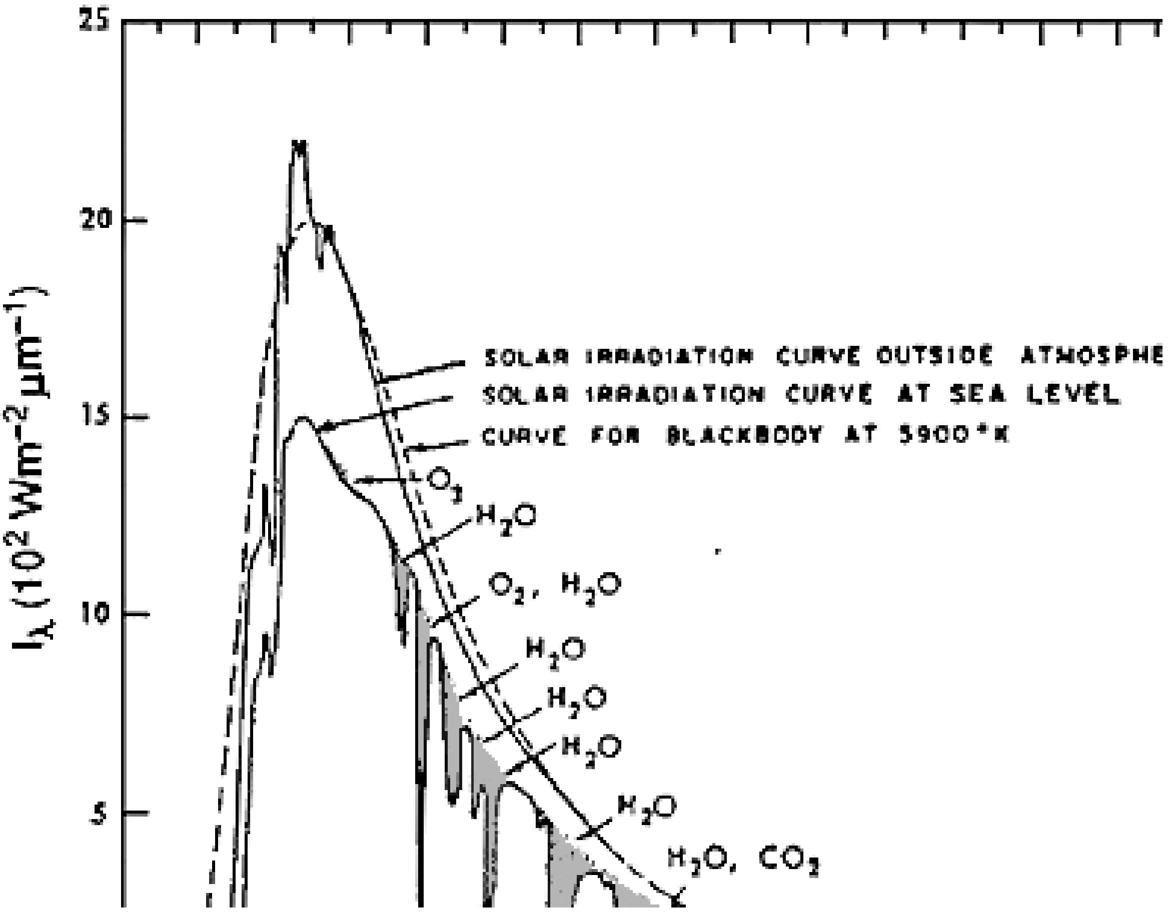


- Below figure shows solar radiation at the top of the atmosphere and the actual radiation at sea level which has been reduced due to absorption by atmospheric gases

- The dashed curve is a blackbody at 5900K for comparison with the solar curve outside the earth's atmosphere

- Shaded areas indicate absorption by atmospheric gases

- Intensity scale is in the order of mWatt or Watt



Atmospheric scattering

- Much of the visible radiation which reaches our eyes is scattered rather than direct

- E.g. light from the sky or from clouds is scattered sunlight
- Atmospheric Scattering is a fundamentally significant process in which incident electromagnetic radiation may be affected by the presence of a particle upon which it is incident

- The particle effectively removes energy from the incoming radiation and reradiates that energy in all directions

- Particles in the atmosphere which are important in scattering are:

  - Gas molecules (size about 1 nm)

  - Solid aerosols (sizes 0.1 to 1.0 µm)

  - Cloud water droplets (1 to 10 µm)

  - Cloud ice crystals (1 to 100 µm)

  - Hail (dolu) (up to 10 cm).

- The directional dependence of the scattering depends very strongly on the ratio of the scattering particle size to the wavelength of the incident radiation

- Isotropic scattering is characterised by a scattering pattern which is symmetrical about the direction of the incoming radiation

- A very small particle tends to scatter light equally in the forward and backward directions relative to the direction of incoming radiation

- Larger particles tend to concentrate most of the scattered radiation in the forward direction

- Several cases to consider:

    1) **Rayleigh scattering**: Occurs when the scattering particle size << λ

       In Rayleigh scattering, the intensity of light is scattered in a particular direction by air molecules is inversely proportional to λ^4

       Rayleigh scattering explains the scattering of sunlight (eg visible and IR wavelengths) by air molecules

       Much of the incoming solar radiation is at visible wavelengths

       The amount of scattering of sunlight at dark blue wavelengths (about 0.47 micron) > for red light (about 0.64 micron) by a factor of $(0.64/0.47)^4 = 3.4$

       This is the reason why the sky appears blue (greater Rayleigh scattering at short visible wavelengths)

       Rayleigh scattering also applies to microwave scattering by raindrops
       Thus used in understanding and interpreting weather radar observations

    2) **Mie scattering**: Occurs when scattering particle size is comparable to or > λ

       Scattering from small suspended particles in the atmosphere (aerosols) like haze, dust, smoke, soot, bacteria, virus, sea salt crystals

    3) **Geometric Optics**: Describe angular distribution of scattered radiation when the scattering particle size >> λ

       Non selective scattering where the scattering is not very dependent on wavelength.

       E.g. to non-selective scattering is scattering of sunlight by atmospheric constituents such as **large** aerosols, cloud droplets or ice crystals. This is why the clouds appear as white or grey

- Consider the size parameter α

$\alpha = 2\pi r/\lambda$

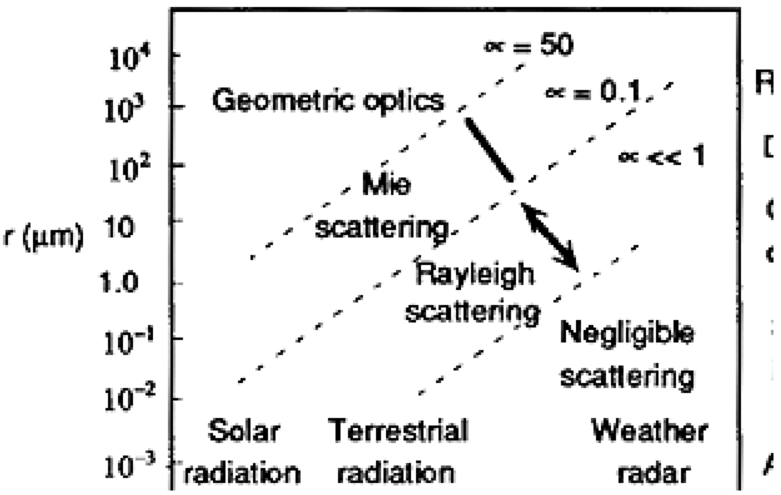
where r is particle radius

Note that α is a dimensionless size parameter which relates the particle size to wavelength of radiation

The ranges of α corresponding to various scattering theories are shown below

α	Scattering
$\alpha > 50$	Describe angular distr
	of scattered radiation
	geometric optics i.e. n
	selective scattering
$0.1 < \alpha < 50$	Mie regime

Below figure shows for various values of scattering particle radius r and wavelength λ



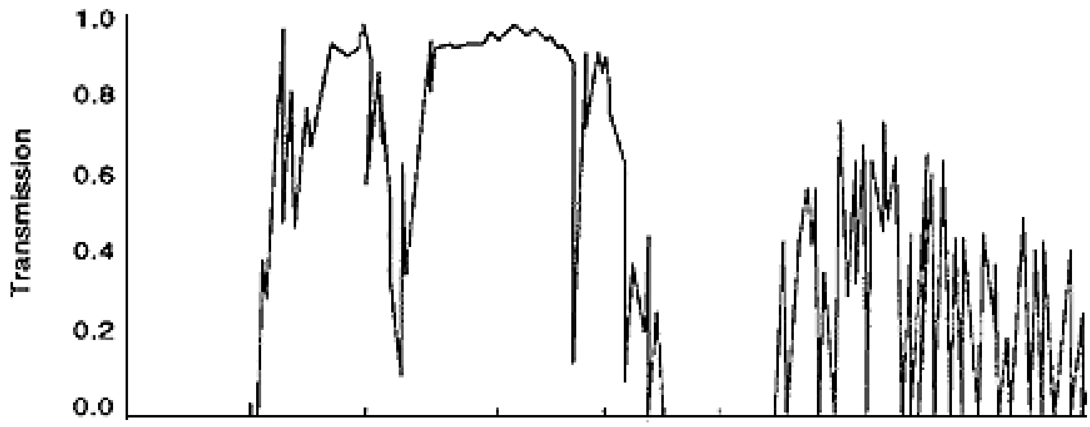
- Scattering of visible radiation in the atmosphere can be significant

- However, scattering of terrestrial (long wave-far inrared) radiation with wavelength >4λ is of secondary importance compared to absorption and emission

- Below Table summarises the main types of atmospheric scattering in the order of importance:

Theory	Particle size	Type of particle	Com
Rayleigh	λ < 0.1	Gas molecules	Scattering inverse
			to fourth power of
			Result: blue sky, r
			sunrise; haze in p
Mie	>= λ	Small cloud droplets,	Generalised theor
		dust, fumes etc	Affects long visibl
Non-selective	>> λ	Cloud droplets, dust etc	Applies to scatteri
			clouds. Scatterin
			independent of λ .
			whitish colour of

- A detailed view is given in the below figure in the form of measured transmittances over the range 5 to 25 microns for the entire atmosphere. This shows that even window regions may be affected by attenuation.



Radiometric Correction of Remotely Sensed Data

- Radiometric correction of remotely sensed data involves the processing of digital images to improve the brightness value magnitudes (as opposed to geometric correction which involves improving the 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

- Radiometric errors and inconsistencies can be referred to as "noise", which could be considered any undesirable spatial or temporal variations in image brightness not associated with variations in the imaged surface

- The sources of radiometric noise and therefore, the appropriate types of radiometric corrections, partially depend on the sensor and mode of imaging used to capture the digital image data

- Several types of imaging systems are utilized for generating digital remotely sensed data, each having their own characteristic sources of radiometric noise

  1) Scanned aerial photography
  2) Optical scanners
  3) Optical linear arrays
  4) Optical framing arrays
  5) Scanning microwave radiometers
  6) Side-looking radars

- Radiance measured by any given system over a given area is influenced by several factors (Some sources of radiometric noise):

  - Spatial variations in illumination quantity and quality
  - Temporal variations in illumination quantity and quality
  - Atmospheric conditions
  - Viewing geometry
  - Instrument response characteristics
  - Sensor-related effects
  - Terrain and surface properties

- Some of these effects are greater with aircraft sensors than with Satellite systems

- Need to apply certain types of corrections depends on the particular application of interest

- In the application of radiometric corrections to digital remotely sensed data:

  - Relative correspondence of image brightness magnitudes may be desired for pixels:

    1) Within a single image (e.g., orbit segment or image frame)
    2) Between images (e.g. adjacent, overlapping frames)
    3) Between spectral band images
    4) between different dated images

- Absolute quantification of brightness values of the pixels are required

- Objective in radiometric correction are:

  - Brightness value inconsistencies caused by the sensor and environmental noise factors are balanced or "normalized" across and between image coverages and spectral bands

  - Retrieval of surface energy properties such as spectral reflectance or surface temperature, which requires absolute radiometric processing

- **Sun corrections**

  - In case regional mosaics using different date images are required or the changes in the ground reflectance are studied, it is necessary to apply corrections for different seasonal positions of the sun

    e.g. Earth - sun distance correction is applied to normalize for the seasonal changes in the distance between the earth and the sun

    Earth - sun distance is usually expressed AU (in astronomical unit = 1.496×10^8 km)

    Irradiance of the sun decreases as the square of the earth-sun distance and expressed as:

    $I_s = (I_0 \cos \theta) / d^2$ where I_s = Normalized solar irradiance, θ is the zenith angle (angle between the line joining the pixel with the sun and the line perpendicular to earth), I_0 is the solar irradiance at θ = 0, d is the distance between the sun and the earth

- **Radiometric Restoration types**

  - **Destriping**

    - Striping or banding occurs if an individual detector used for a particular band goes out of adjustment

    - This brings systematic noise in an image that results from variation in the response of the a detector

    - Result is that the detector provides readings that are consistently greater than or less than the other detector's readings for the same band over the same ground area

    - In the case of MSS (Multispectral Scanner) data, there are 6 detectors per band which scan in a side to side motion

    - If one of the detectors is miscalibrated, then horizontal banding occurs on each 6^{th} line

- Similarly, in the case of TM data with 16 detectors per band, each 16th line in the image will be affected

- Multispectral SPOT data have a pushbroom scanner with 3000 detectors for each band, one detector for each pixel in a row

- Since detectors in a pushbroom scanner are arranged in a line perpendicular to the satellite orbit tack, miscalibration in SPOT detectors produces vertical banding

- Procedure that corrects the values in the bad scan lines is called destriping

- Destriping involves the calculation of the mean (or median which is the value that divides the data values into two equal parts) and standard deviation {$\sigma = [\Sigma (x_i - \upsilon)^2]^{1/2}$ where υ is the mean value and the summation is from i=1 to N} for the entire image and then for each detector separately

- Some software packages offer an option for applying a mask to the image to exclude certain areas from these calculations (for example, clouds and cloud shadows should be excluded)

- Also, sometimes only a portion of the image, usually a homogeneous area, such as a body of water, is used for these calculations

- Then, depending on the algorithm employed by a software system, one of the following adjustments is usually made:

    - The output from each detector is scaled to match the mean and standard deviation of the entire image. In this case the value of each pixel in the image is changed

    - The output from the problem detector is scaled to resemble the mean and standard deviation of the other detectors. In this case the values of the pixels in normal data lines are not altered.

Destriping Example:

- In this exercise, destriping technique with a certain SPOT data will be explored

- The data set includes three multispectral bands (B1, B2,B3) with 20 x 20 m resolution

- Two false color composites will be created

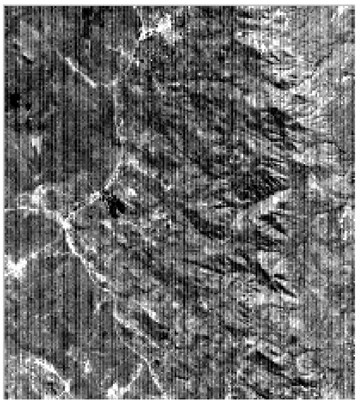
    - First, using the raw bands

    - Second, using destriped bands

- Comparison of these two images will show how efficient destriping techniques can be for the removal of systematic noise in the data

Procedure:

5) Examine the below B2 (red band) image (vertical stripes are noticed)



6) Create a false color composite image using NJOLOV1 as the blue band, NJOLOV2 as the green band, and NJOLOV3 as the red band

Specify a linear stretch with 0.5 % saturation. Call the output image NJOLOVFC

As seen below the stripes are even more clear

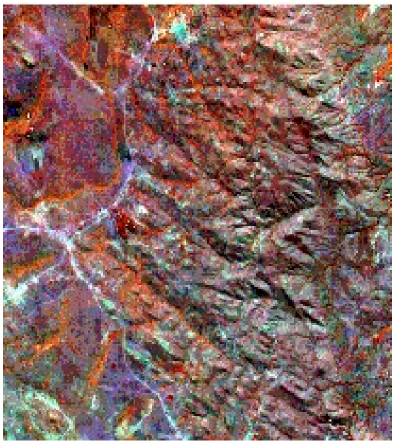
7) Through a software algorithm, apply destriping procedure to each of the three raw bands

8) Create a false color composite image using the three destriped images, destiped B1 as the blue band, destriped B2 as the green band and the destriped B3 as the red band

Specify a linear stretch with 0.5 % saturation

Resultant false color composite image is displayed below

For comparison, false color composite of the raw bands is also shown below



Line dropout

- Data error that occurs when a detector in a satellite scanner either:

  Completely fails to function, or

  Temporarily misfunctions during a scan

- The result is a line, or partial line, of data with incorrect data files

- Thus the values create a horizontal streak until the detector(s) recovers

Signal noise

- Noise refers to any unwanted or extraneous energy detected by the sensor which will disturb the image

- Noise is the result of limitations in the sensing, signal digitization or data recording

- Noise can either degrade or totally mask the true radiometric information content of a digital image

- It is expressed by the signal-to-noise ratio (SNR)

- SNR directly affects the ability to detect small radiometric differences in the data

Atmospheric effects

- İncoming and outgoing radiation interact with the atmosphere which produce errors in the brightness values

- These errors are not similar to sensor errors because atmospheric events appear as part of the detected radiance

- Quite often it is important to remove or reduces these unwanted atmospheric effects

- Atmosphere affects radiance at any given point on the image in two ways:

1) Attenuates the energy that illuminates the ground object.

2) Acts as a reflector itself, adding a scattered, extra path radiance to the signal detected by the sensor.

- Scattering factor introduces haze into the image

- Scattering effect can be minimizes using haze compensation routines

Haze compensation

- Procedures are developed to compensate for the effects of scattering or haze which are designed to minimize the influence of path radiance effects

- These procedures are usually applied uniformly over the entire scene

- Most widely used procedures are:

  - **Dark pixel removal** - Studies areas with zero reflectance, like water, to see what brightness shifts have occurred.

  - **Linear regression** - Statistically compares the scattering in two bands, usually the blue (most scatterering) and mid ir (least scattering)

Radar Despeckling

- Radar imagery is particularly susceptible to the introduction of image noise called speckle (that occurs due to random interference of microwaves) which is responsible for the "grainy" appearance of SAR imagery

- Variety of image filters are used to remove these unwanted speckle effects

Radiance Conversion

- Pixel values in commercially available satellite imagery represent the radiance of the surface in the form of Digital Numbers (DN), (e.g. 256 levels) which are calibrated to fit a certain range of values

- DN are referred to as the brightness values

- Conversion of DN to **absolute radiance** values is a necessary procedure for comparative analysis of several images taken by different sensors (for example, Landsat-2 versus Landsat-5)

- Since each sensor has its own calibration parameters used in recording the DN values, the same DN values in two images taken by two different sensors may represent two different radiance values

- Usually, detectors are calibrated so that there is a linear relationship between DN and spectral radiance

- This linear function is described by three parameters:

- The range of DN values in the image. Mostly, the data is in 8-bit format corresponding to 256 DN levels

- The lowest (L_{min}) radiances measured by a detector over the spectral bandwidth of the channel

- The highest (L_{max}) radiances measured by a detector over the spectral bandwidth of the channel

- L_{min} is the spectral radiance corresponding to the minimum DN value (usually, value of 0)

- L_{max} is the radiance corresponding to the maximum DN (usually, value of 255)

- **Not only each sensor, but each band within the same sensor, has its own Lmin and Lmax**

- The specifications about sensor calibration parameters (L_{min} and L_{max}) are usually supplied with the data or is available elsewhere (e.g., Landsat Data User's Handbook)

- The equation relating DN in remotely sensed data to radiance is:

$$\mathbf{L = (L_{max} - L_{min})/255 * DN + L_{min}}, \qquad \text{Eq. (1)}$$

where L is the the radiance expressed in (W m^{-2} sr^{-1})

- In this exercise two MSS images taken by different satellites will be compared

- At first, one image will be subtracted from another

- The resulting image will have values represented in DN

- Then, these images will be converted into absolute radiance images and perform image differencing on them

- The resulting image will have values represented in radiance units

- Finally, two difference images will be compared to see how the radiance conversion influences the results of change analysis.

<u>The Data Set</u>

- The data set consists of two infrared bands (0.8-1.1 micrometers) of MSS imagery

- First image, BAND475, was taken by Landsat-2 on December 12, 1975

- The second, BAND484, by Landsat-5 on November 11, 1984

- Both images are georegistered and have the resolution of 60x60 meters

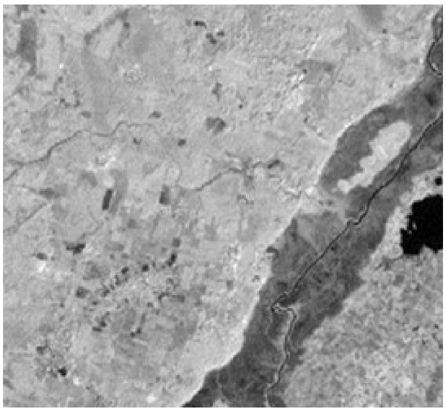
- The DN values in both images range from 0 to 255

Procedure

1) Simultaneously display BAND475 and BAND484 images

Band 4, 1975

Band 4, 1984



2) Subtract BAND484 from BAND475

The value of any pixel in this image corresponds to the difference in DN values for this pixel in BAND475 and BAND484

Calculate the mean value of the difference image

Now convert the DN values in the two bands into radiance units

For conversion, values of L_{min} and L_{max} for the satellites should be known

The following table lists these values for MSS band 4 for the two satellites:

Sensor	L_{min}	L_{max}
Landsat-2 MSS (on or after 07/16/75)	0.6	15.2
Landsat-5 MSS (on or after 11/9/84	0.3	12.3

Using these values in the conversion equation (1) above, absolute radiance values for each pixel in the two images can be calculated

For the first image (BAND475) the equation will be in this form:

L_1 = (15.2-0.6)/255*BAND475 + 0.6 Eq. (2)

i.e.

L_1 = 0.0572549 * BAND475 + 0.6 Eq. (3)

Similarly, for the second image (BAND484) the equation can be written as:

L_2= (12.3-0.3)/255 * BAND484 + 0.3 Eq. (4)

i.e.

L_2 = 0.0470588 * BAND484 + 0.3 Eq. (5)

3) Using equations (3) and (5), convert BAND475 and BAND484 into radiance images RAD475 and RAD484

4) Examine the range of values in RAD475 and RAD484 images which represent the absolute radiance values

   Notice that the radiance values are real numbers, while the DN values in BAND475 and BAND484 are integers.

5) Subtract RAD484 from RAD475

   Calculate the mean value of this image (difference of the radiance)

<u>Observations</u>

- Mean value in both difference images is not zero

- This suggests that there is an overall change between the two dates

- In the case of the difference image between the DN images, the mean is less than zero (-10.3086) suggesting that there was an overall negative change in reflectance values in the area

- In the case of the difference image between the radiance images, however, the mean is above zero (0.2303) suggesting that there was an overall positive change in reflectance values in the area

- So, which of the two conclusions correspond to reality? The latter, because it is based on the comparison that takes into account the difference in calibration parameters of the satellites, while the former assumes no difference in satellites between the two time periods.

- Conclusion: This example illustrates that conversion of DN values to absolute radiance is an important step in quantitative analysis of change when satellite data from different time periods are employed

Geometric Correction of Remotely Sensed Data

- Geometric errors in the digital images collected from airborne or spaceborne sensors:

  - Systematic geometric errors

  - Unsystematic geometric errors

- **Systematic Errors:**

- Scan Skew: Caused by the forward motion of the platform during the time required for each mirror sweep. The ground swath is not normal to the ground track but is slightly skewed, producing cross-scan geometric distortion

- Mirror-Scan Velocity Variance: The mirror scanning rate is usually not constant across a given scan, producing along-scan geometric distortion

- Platform Velocity: If the speed of the platform changes, the ground track covered by successive mirror scans changes, producing along-track scale distortion

- Earth Rotation: Earth rotates as the sensor scans the terrain. This results in a shift of the ground swath being scanned, causing along-scan distortion

- **Nonsystematic Errors**

  - Altitude Variance: If the sensor platform departs from its normal altitude or the terrain increases in elevation, this produces changes in scale

  - Platform Attitude: One sensor system axis is usually maintained normal to Earth's surface and the other parallel to the spacecraft's direction of travel. If the sensor departs form this attitude, geometric distortion results

- Errors like scan skew, mirror-scan velocity variance, platform velocity can be corrected by using ephemeris (any tabular statement of the assigned places of a celestial body for regular intervals. E.g., the solar ephemeris provides the exact location of the sun at any given time of the day or year) of the platform and known sensor distortion characteristics

- Altitude Variance and Platform Attitude Errors can be corrected by matching image coordinates of physical features recorded by the image to the geographic coordinates of the same features collected from a map or global positioning system (GPS)

Definition of some geographic correction terms

- Ground Control Point (GCP): A specific pixel on an image or location on a map whose geographic coordinates are known. GCP's are used to correct geometric distortion in an image by matching image coordinates with map coordinates. Image and map coordinates are used to compute the transformation matrix for use in rectifying the image

- Linear Transformation: The transformation of coordinates from one system to another (image to map) using a linear algebraic (1^{st} order polynomial) formula

- Non-Linear Transformation: The transformation of coordinates from one system to another (image to map) using a non-linear algebraic (n^{th} order polynomial) formula

- Rectification: The process by which the geometry of an image is made planimetric

- Registration: The process of geometrically aligning two or more sets of image data such that resolution cells for a single ground area can be digitally or visually superimposed

- Resampling: The process of extrapolating data values to a new grid. Resampling is the step in rectifying an image that calculates pixel values for the rectified grid from the original data grid

- Root Mean Square Error (RMS):The RMS Error is the error term used to determine the accuracy of the transformation from one coordinate system to another

Image to Ground Geocorrection

The correction of digital images to ground coordinates using ground control points collected from maps or ground GPS recognaisance.

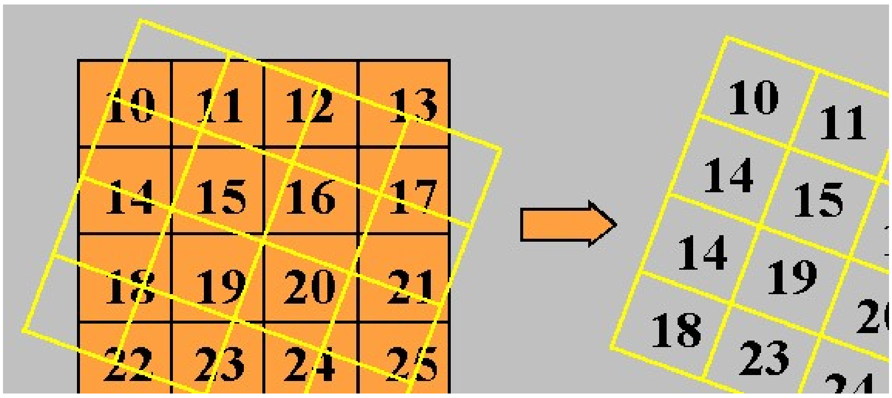
Image to Image Geocorrection

Image to Image correction involves matching the coordinate systems of two digital images with one image acting as a reference image and the other as the image to be rectified.

<u>Image Resampling Methods:</u>

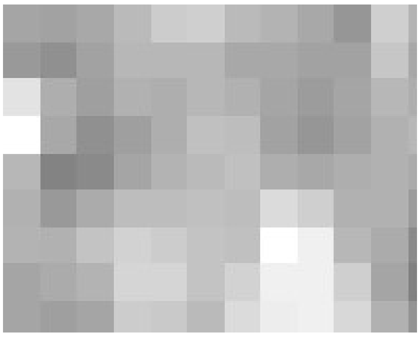
1. Nearest Neighbour Resampling Method

- Nearest neighbour approach uses the value of the closest input pixel for the ouput pixel value. An example:

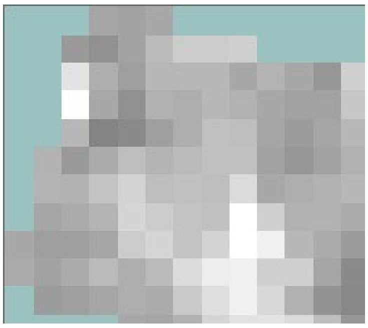


In the above figure:

- Input file (orange) is superimposed with the output file (yellow)
- Input values closest to the center of each output cell are sent to the output file to the right
- Notice that values 13 and 22 are lost while values 14 and 24 are duplicated
- This loss of data may result in breaks in linear features such as roads, streams, and boundaries



Unrectified raster image



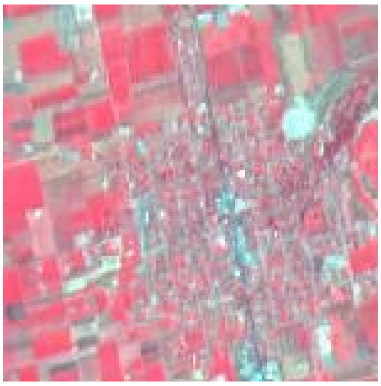
Rectified using nearest neighbour resampling

Row	0	1	2	3	4	5	6	7	8	9	10
0	55	59	63	69	73	69	61	60	58	58	75
1	56	54	60	67	65	62	59	60	57	59	73
2	81	64	61	64	62	66	64	61	56	57	67
3	85	60	56	60	63	72	69	61	58	61	66
4	61	51	57	63	66	69	70	66	65	65	63
5	62	62	70	71	68	70	69	83	76	61	63
6	66	69	74	75	72	71	71	95	85	64	61
7	60	63	69	75	75	72	74	81	81	71	58
8	58	58	61	71	71	68	74	79	81	76	[illegible]

Brightness value matrix of unrectified image

Row	0	1	2	3	4	5	6	7	8	9	10	11	12
0				55	59	63							
1			56	54	60	69	73	73	69				
2			81	64	61	67	65	62	59	60	58	58	75
3			85	60	56	64	62	66	64	60	57	59	73
4			61	51	57	60	63	72	69	61	56	57	67
5		62	62	70	71	66	69	70	70	61	58	61	66
6		66	69	74	75	68	70	69	83	65	65	63	67
7		60	63	69	75	72	71	71	95	76	61	63	64
8	58	58	58	61	71	75	72	74	95	85	64	61	58
9	58	59	61	62	61	68	74	79	81	71	71	58	52
10		58	57	59	61	63	70	80	81	76	66	59	53

Brightness value matrix of nearest neighbour resampled image



- To determine the nearest neighbor, the algorithm uses the inverse of the transformation matrix to calculate the image file coordinates of the desired geographic coordinate

- The pixel value occupying the closest image file coordinate to the estimated coordinate will be used for the output pixel value in the georeferenced image

Advantages of Nearest Neighbour Resampling Method:

- Output values are the original input values. Other methods of resampling tend to average surrounding values

- Easy to compute, thus fastest to use

Disadvantages of Nearest Neighbour Resampling Method:

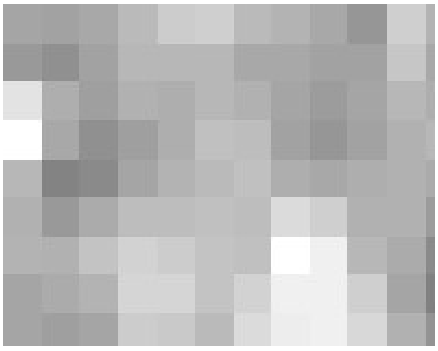
- Produces a choppy, "stair-step" effect. The image has a rough appearance relative to the original unrectified data

- Data values may be lost, while other values may be duplicated

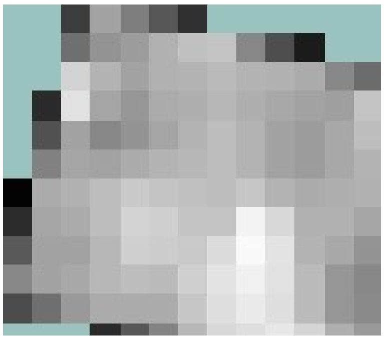
2. Bilinear Interpolation Resampling Method

- Bilinear interpolation approach uses the weighted average of the nearest four pixels to the output pixel

- İ.e. the brightness values from four pixels (those to the right, left, above and below the spot where the new pixel is to be created) are added, then the sum is divided by four to create the new brightness value



Unrectified raster image



Rectified using nearest Bilinear Interpolation

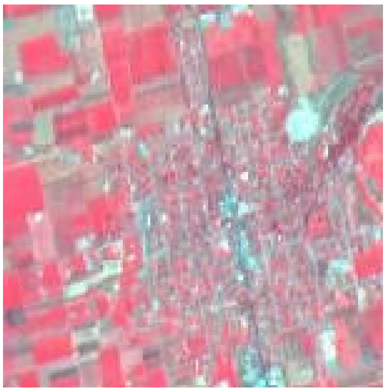
- Notice the dark edge cells created by averaging zero values located around the perimeter of the ouput file into real data values

Row	0	1	2	3	4	5	6	7	8	9	10
0	55	59	63	69	73	69	61	60	58	58	75
1	56	54	60	67	65	62	59	60	57	59	73
2	81	64	61	64	62	66	64	61	56	57	67
3	85	60	56	60	63	72	69	61	58	61	66
4	61	51	57	63	66	69	70	66	65	65	63
5	62	62	70	71	68	70	69	83	76	61	63
6	66	69	74	75	72	71	71	95	85	64	61
7	60	63	69	75	75	72	74	81	81	71	58
8	58	58	61	71	71	68	74	79	81	76	66

Brightness value matrix of unrectified image

Row	0	1	2	3	4	5	6	7	8	9	10	11	12
0			21	56	47	33	17						
1			40	55	58	65	70	68	45	26	9		
2			74	66	61	65	65	63	61	60	59	50	41
3		14	76	60	58	62	62	66	62	60	57	59	71
4		28	58	54	59	62	66	70	66	60	56	59	69
5		46	63	66	67	66	68	70	67	61	60	63	66
6	1	62	68	73	73	70	70	69	74	69	65	64	65
7	16	60	64	71	75	73	71	72	89	78	62	63	61
8	31	58	59	66	73	73	73	77	87	80	63	60	55
9	46	59	60	63	66	67	72	77	81	76	65	56	52
10	25	41	55	60	62	63	69	78	80	78	68	58	55

Brightness value matrix of Bilinear Interpolation resampled image



Advantages of bilinear interpolation resampling:

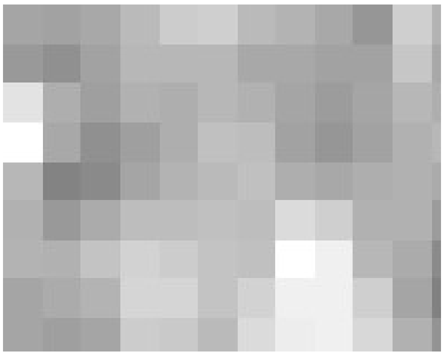
- Stair-step effect caused by the nearest neighbor approach is reduced
- Image looks smooth

Disadvantages of bilinear interpolation resampling:

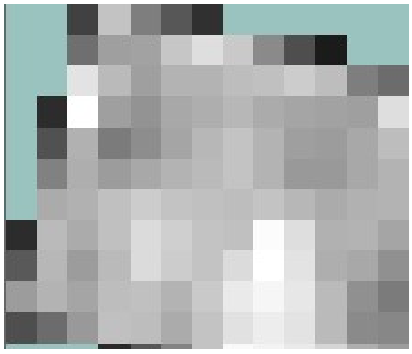
- Alters original data and reduces contrast by averaging neighboring values together
- Computationally more expensive than the nearest neighbour

3. Bicubic Convolution Resampling Method

- In the bicubic convolution case, **a distance-weighted average** of the 16 nearest old cells is assigned to the new cell
- The corresponding brightness values are added and then averaged
- Averaging can also be on weighted basis giving preference for the predominant brightnesses
- The output is similar to bilinear interpolation, but the smoothing effect caused by the averaging of surrounding input pixel values is more dramatic



Unrectified raster image



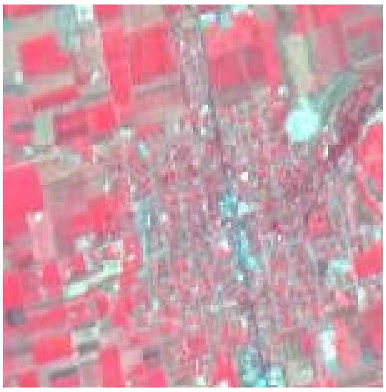
Rectified using bicubic convolution resampling

Row	0	1	2	3	4	5	6	7	8	9	10
0	55	59	63	69	73	69	61	60	58	58	75
1	56	54	60	67	65	62	59	60	57	59	73
2	81	64	61	64	62	66	64	61	56	57	67
3	85	60	56	60	63	72	69	61	58	61	66
4	61	51	57	63	66	69	70	66	65	65	63
5	62	62	70	71	68	70	69	83	76	61	63
6	66	69	74	75	72	71	71	95	85	64	61
7	60	63	69	75	75	72	74	81	81	71	58
8	58	58	61	71	71	68	74	79	81	76	66

Brightness value matrix of unrectified image

Row	0	1	2	3	4	5	6	7	8	9	10	11	12
0			23	66	47	33	17						
1			41	60	60	74	81	69	45	25	9		
2			79	68	61	65	65	64	65	68	64	48	41
3		14	86	58	57	62	62	65	61	61	57	59	82
4		26	63	51	57	62	67	72	66	59	55	59	70
5		45	67	65	67	67	68	71	66	59	59	63	67
6		62	69	74	75	70	70	68	73	70	65	64	66
7	16	67	63	72	76	73	71	71	93	81	62	63	62
8	30	65	58	67	76	73	72	77	92	80	61	61	54
9	52	65	60	64	66	66	71	77	81	79	64	53	49
10	27	41	55	67	68	64	68	78	81	80	67	55	54

Brightness value matrix of bicubic convolution resampled image



Advantages of the bicubic convolution resampling method:

- Stair-step effect caused by the nearest neighbor approach is reduced. Image looks smoother

Disadvantages of the bicubic convolution resampling method:

- Alters original data and reduces contrast by further averaging neighboring values
- Computationally more expensive than nearest neighbor or bilinear interpolation

Geometric Restoration Exercise:

1) Merging Data with Varying Resolutions

- Merging of different data sets is often used in digital image processing to improve the visual and analytical quality of the data
- It may be needed to merge different types of data, such as:
    - Satellite imagery from the same sensor but with different resolution (e.g. SPOT 10x10 m panchromatic (black,white) data with SPOT 20x20 m multispectral data)
    - Satellite imagery from different sensors with varying resolution (e.g. Landsat 30x30m TM data and Landsat 79x79m MSS data)
    - Digitized aerial photography and satellite imagery (e.g. aerial photography with 15x15m resolution and SPOT 20x20 m multispectral data)
    - Satellite imagery with ancillary information (e.g. Landsat 30x30 m TM color composite and 70x70 m Digital Elevation Model)
- Before merging can be done, the initial data need to be processed to have:

i) The same reference system

ii) The same resolution

iii) The coverage of the same geographical area (the same minimum and maximum x and y-coordinates)

- First, the images have to be accurately georegistered to the same reference system and to one another

- Then the common geographical area between the two images has to be determined and extracted (windowed) from the original images so that the resulting windows have the same minimum and maximum X and Y coordinates

- Finally, the images have to be transformed to have the same dimensions and resolution

- This usually can be done via resampling

- In cases when the ratio between the number of rows (columns) in one image and the number of rows (columns) in the other image is an integer number, then the image with coarser resolution can be expanded by this integer number to match the dimension of the other image

- Both resampling and the latter procedure will automatically calculate the new cell resolution

- Some of the other alternatives for data merging:

    - Color space transformation and substitution method

    - Simple band substitution

    - Principle component substitution

    - Band-by-band merging (via addition)

Geometric Restoration Exercise:

2. Image-to-Image Geocorrection

- Geometric correction is used for a variety of operations like:

    - Referencing an unreferenced or arbitrarily referenced image to a universally recognized coordinate reference system such as Lat/Long or Universal Transverse Mercator (UTM)

    - Co-registering multiple images that were collected at different times or from different sources for the purpose of change analysis

    - Making non-integer changes in the resolution of an image.

<u>Image rectification and registration procedure:</u>

1. Identify x, y-coordinates of several pairs of points (called ground control points) that represent the same places within both the old and new coordinate systems

   The coordinates of the new system may be taken from:
   - A map
   - Another already georeferenced image

- A vector file
- Through surveying either with traditional instruments or with GPS

2. Solve the equations that describe the relationship between the two coordinate system (using the ground control points information) to produce two equations for the conversion of the X and Y coordinates from the "old" reference system to the "new" one

3. Using these equations, convert the entire image to the new reference system through transformation process including both:

   - Spatial interpolation (e.g., coordinate transformation) and

   - Intensity interpolation (e.g., pixel brightness transformation).

The Data Set

- In this exercise, one satellite image will be registered to another

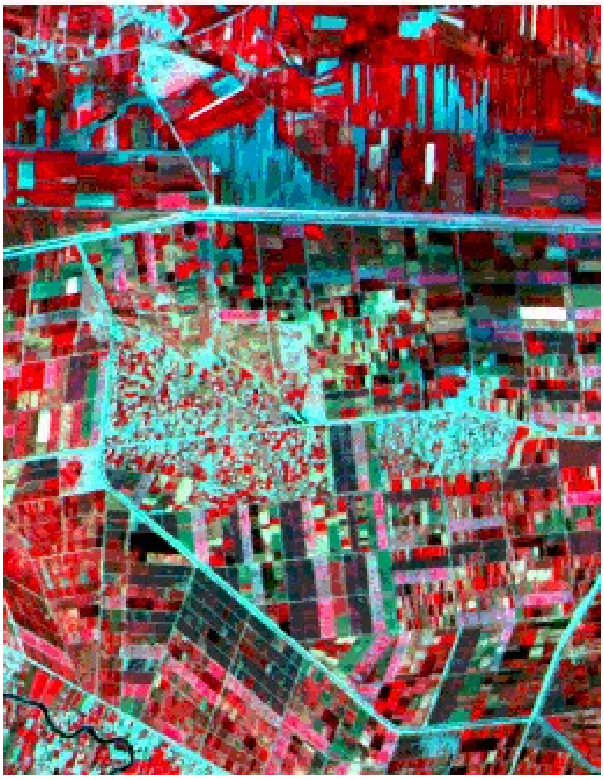
- Both of the images are false color composite images derived from SPOT multispectral images. The images are MAY (taken on May 10, 1986) and JUNE (June 13, 1986)

Procedure

1. Examine the images JUNE and MAY simultaneously

   Select a prominent road intersection and examine its x and y coordinates on both images

May image



June image

- You will notice that the images differ slightly in position and orientation. To be able to analyze changes between these images, first we have to make sure that the corresponding pixels of each image actually describe the same location on the ground

- Registering these images is done using a process known as rubber sheet resampling

- Consider the JUNE image to be the reference image and register the MAY image to it

- As the first step in the registration procedure, find the points that can be easily identified within both images

- Places that make good control points include road and river intersections, dams, airport runways, prominent buildings, mountain ridges or any other obvious physical feature

- x, y-coordinates of these points in the JUNE image will be the "new" coordinate pairs while the coordinates from the MAY image will be the "old" coordinate pairs

- Two issues are critical during this phase of the process:

  i) Obtaining a good distribution of control points

  - Points should be spread evenly throughout the image because the equation that describes the overall spatial fit between the two reference systems will be developed from these points

  - If the control points are clustered in one area of the image then the equation will only describe the spatial fit of that small area and the rest of the image will not be accurately positioned during the transformation to the new reference system

  - A rule of thumb is to try to find points around the edge of the image area

  - However, if you are only interested in part of the image then you may concentrate all the points in that area and then window out that area during resampling

  ii) Recording the confidence of positional accuracy

  - While locating points, draw a small sketch of the area, mark each control point position on the sketch with an identifier and record your level of confidence in the positional accuracy of each of the points (e.g., poor, fair, good)

  - In the resampling process, it will be possible to omit points from the equation that don't fit the equation well

  - In order to retain a good distribution and high confidence in the remaining control points, remember their positions in the image and their relative positional accuracy

2. Find 10 -12 control points that may be precisely located and are well distributed around the image

Record the x and y-coordinates of each control point in both images

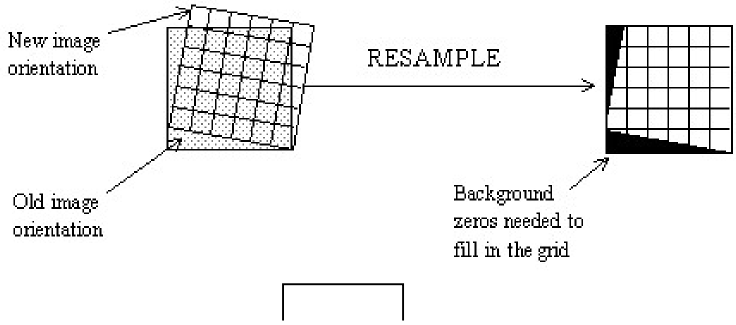
3. Display the MAY image and overlay the control points on top of the image (as seen below the control points are uniformly distributed around the image)

In the next step, the best fit equation between the two images will be calculated.

4. Apply resampling. Specify MAY as the input image to be resampled

5. Specify 0 as background value

A background value is necessary because after fitting the MAY image to the JUNE image, the actual shape of the data may be angled. In this case, some value needs to be put in as a background value to fill out the grid. The value zero is a common choice. This is illustrated in the below Figure



6. Select the geographic region that covers the output image

   To define the area of interest, specify the bounding rectangle by fixing minimum and maximum x and y's which are taken from the JUNE image as:

   Min x = 3840
   Max x =10240
   Min y = 1220
   Max y = 9620

7. Determine the number of columns and rows for the output image

   In some cases it is assumed that the cell resolution will remain the same and the number of rows and columns are calculated automatically

   In other cases, the resolution of the output image is changed and the number of rows and columns are found accordingly

   Number of columns for the new image is calculated using the following equation:

   # Columns = (Max x - Min x) / Resolution

   In this exercise, 20 meter resolution for the output image will be kept

   Thus # columns in the new image = (10240 - 3840) / 20 = 320.

   Similarly, the number of rows for the new image is found as

   # Rows = (Max y - Min y) / Resolution = 420

8. Apply resampling, either bilinear and nearest neighbor resampling

   Process of image-to-image registration is like laying the new image in its correct orientation on top of the older image

   Values are then estimated for each new cell by looking at the corresponding cells underneath it in the old image

   One of following three basic logics can be used for the estimation:

   i) Nearest neighbour rule: The nearest old cell (based on cell center position) is chosen to determine the value of the new cell. Nearest neighbor resampling should be used when the data values cannot be changed, e.g, with categorical data or qualitative data such as soils types

   ii) Bilinear interpolation: A distance weighted average of the four nearest old cells is assigned to the new cell. The bilinear interpolation is appropriate for quantitative data such as remotely sensed imagery

   iii) Bicubic convolution: A distance weighted average of the 16 nearest old cells is assigned to the new cell. Bicubic convolution is appropriate for quantitative data such as remotely sensed imagery

9. Fix the order of polynomial fit desired for the mapping function:

   - Linear (first order) or,
   - Quadratic (second order) or,
   - cubic (third order)

   For this exercise select the linear function

   The linear mapping function is commonly used with images about this size or smaller

   Higher-order mapping functions (quadratic and cubic) are used with larger images

   A minimum number of control points are required for each of the mapping functions:

   - 3 for linear
   - 6 for quadratic
   - 10 for cubic

   In this exercise, the number of points found (12) better reflects the quantity that should be found for the surface area of MAY with the linear mapping function

10. Calculate the total root mean square (rms) error of the control points and the individual residual errors of each control point

    These residuals express how far the individual control points deviate from the best fit equation

    Best fit equation describes the relationship between the image's reference system and the new reference system into which it will be resampled

    This relationship is calculated from the control points. A point with a high residual suggests that the point's coordinates were ill chosen, in either the "old" system, the "new" system, or both

    Total rms describes the typical positional error of all the control points in relation to the equation. It describes the probability that a mapped position will vary from the true location

    According to some map accuracy standards, the rms for images should be less than 1/2 the resolution of the input image

    In this case, rms should be less 10 m

11. View the residual errors of all the control points

    Some points have higher residuals than the others which is not unexpected or uncommon

It is not always easy to know which pixel to pick for a control point or whether to pick the cell center or one of its edges

Bad points can be omitted, a new equation can be calculated

Before omitting points, maintain a good distribution of points and retain those points in which you have the highest confidence

While those points with a very high rms value tend to be poor, this is not always the case

Few bad points in another part of the image can "pull" the equation and make one good point appear bad

12. When the setting of control points and the overall rms (less than 10) are satisfactory, calculate the transformation equation and complete the resampling process

    Transform the entire image into the new reference system according to the equation

13. Display and examine the resampled MAY image as a false color composite image

Now these two images (Resampled MAY image and JUNE image - are coregistered and can be used for any type of change analysis.

Resampling can be time-consuming, however, the level of care with which it is done affects subsequent analyses that use the registered data

10. Interpretation of Digital Image Data

- Some Definitions

- **Photo Interpretation:** Examining the aerial photographs/images for the purpose of identifying objects and judging their significance
- **Photography:** Process of producing images on a sensitized surface by the action of light or other radiant energy
- **Image:** Optical counterpart of an object produced by a lens or mirror or other optical system
- **Photogrammetry:** Science of obtaining reliable measurements by means of photography

Airphoto/Image Interpretation Activities

- **Detection and Identification** of objects, features, phenomena and processes. Based on his response, interpreter puts labels reflecting some qualitative terms as. likely, possible, probable or certain ..etc

- **Measurement:** Taking quantitative measurement, however techniques used by interpreters are not as precise as the measurements taken by photogrammetrists using sophisticated instrumentation

- **Problem Solving:**

  - Identifying objects from a study of associated objects

  - Identifying object complexes from an analysis of their component objects

  - Finding out the effect of some process and suggesting a probable cause.

  - Answer may be expressed as a number of likely scenarios with certain probabilities of correctness

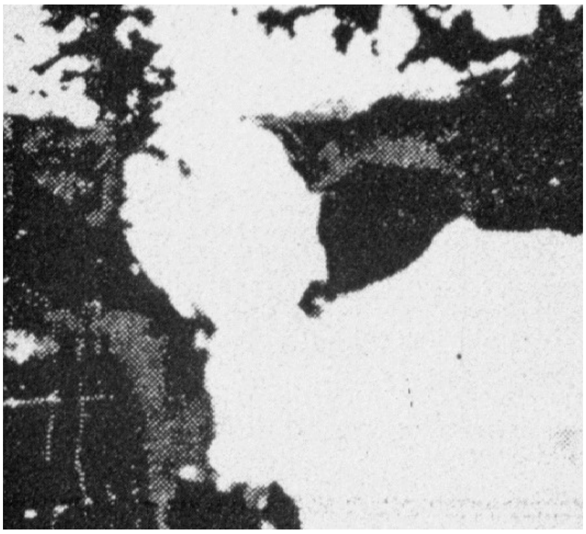
Elements of Image Interpretation

1. First Order (Basic) Elements of Image Interpretation

i) Tone/Color:

Tone: Each distinguishable variation from white to black

Examples of tone are shown below:



Color: Each distinguishable variation on an image produced by a multitude of combinations of hue (kind, variety), brightness value and chroma

Example of color is shown below:

ii) **Resolution:** Is the ability of the entire photographic system (including lens, exposure, processing and other factors) to yield a sharply defined image.

In interpretation, resolution is usually given in terms of ground resolved distance which is the smallest contrast object that can be detected and identified on a photo

2.1. Second order (Geometric Arrangements of Objects) Elements of Image Interpretation

i) **Size:**

- Used in discrimination of objects and features (e.g. cars vs. trucks or buses; bush (çalılık) versus trees, etc.)

- Used as a diagnostic characteristic in which both the relative and absolute sizes of objects are important

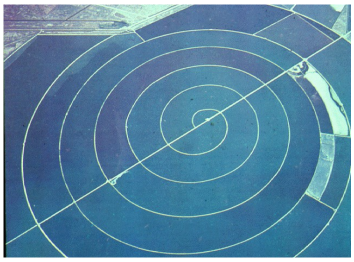
- Also used in judging the significance of objects and features (e.g. size of agricultural fields related to water use in arid (kurak) areas; size of runways gives an indication of the types of aircraft that can be accomodated)

ii) Shape of objects/features provide diagnostic clues that aid identification

- Man-made features have straight edges, however natural features do not

- Roads can have right angle turns, railroads do not.

Examples of shape are given below:



2.2. Second order (Spatial Arrangement of Tone/Color) Elements of Image Interpretation

i) Texture: Frequency of change and arrangement of tones.

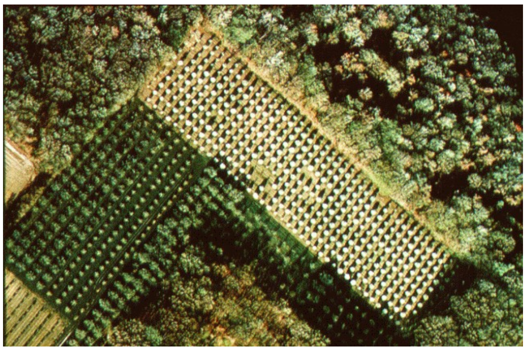
- Texture is a micro image characteristic

- Water bodies are typically fine textured

- Grass is medium textured

- Bush is rough textured.

Example of texture is shown below:

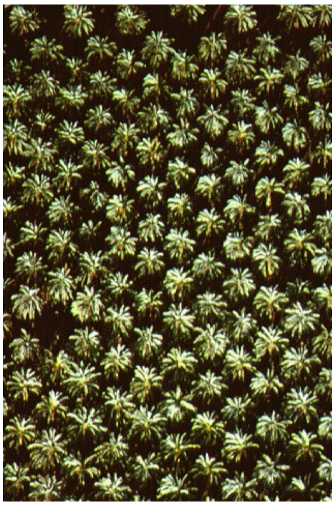


ii) **Pattern:** Spatial regular arrangement of objects that can be diagnostic of features on the landscape

- Can be either man-made or natural

- Macro image characteristic

Example of pattern is given below:



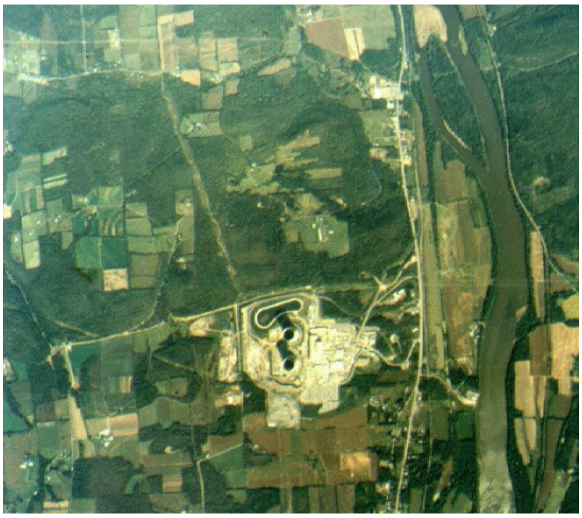
3.1 Third order (Locational or Positional Elements) Elements of Image Interpretation

i) **Site** – Arrangement of objects with respect to one another or with respect to various terrain features

- Distinctive factors of site are aspect, topography, geology, soil, vegetation and cultural features on the landscape

- Relative importance of each of the above distinctive factors vary with local conditions

Example of site:



ii) **Association:** Some objects are so commonly associated with one another that identification of one tends to indicate or confirm the existence of another. E.g:

- Aluminum manufacture requires large amounts of electrical energy. Absence of a power supply may rule out this industry

- Schools have characteristic playing fields, parking lots and clusters of buildings in urban areas

3.2.Third order (Interpreted from lower order elements) Elements of Image Interpretation

i) **Height:** E.g. Measure of deepness of mining excavation indicates the amount of material that was removed

ii) **Shadow** – Results in low sun angle photography

Aids and Techniques of Image Interpretation

- **Collateral Material:**

  - Review of existing collateral material (data of many types existing in either analog or digital form) concerning a given area, process; type of facility, or object can aid in the interpretation of remotely sensed data

  - Collateral material can be in the form of text, tables, maps, graphs or image data/information

  - Material contained within a Geographic Information System (GIS) used to assist an interpreter in an analysis can be considered collateral data

  - Two classes of collateral data are of interest:

    1. **Collateral Data Class: Photo/Image Interpretation Keys**

       - A set of guidelines used to assist interpreters in rapidly identifying photo/image features

       - Selective keys or elimination keys (precise step-wise process that leads to the elimination of all items except the one (ones) that is being identified) are used

    2. **Collateral Data Class: Field Verification**.

       - Used to familiarize the interpreter with the area or type of feature or object to be interpreted

Use of Multiple Images

- Multi-Station: Successive overlapping of photographs taken along a given flight line by an aircraft or a satellite.

- Multi-Band: Individual spectral bands within a given region of the EM spectrum (e.g. the red, green, and blue bands of the visible)

- Multi-Spectral: Images from various regions of the EM spectrum (e.g. visible, infrared and microwave)

- Multi-Date: Images of a given area taken at different times

- Multi-Stage: Acquisition of images from platforms flying at different altitudes (e.g. data by low flying aircraft, high flying aircraft and satellite data in a given study)

- Multi-Polarization: Different objects exhibit different rotation to the signal when returned to the sensor

- Multi-Direction: Most sensors employed in remote sensing are aimed vertically except SAR. Sometimes more information can be obtained by using non-vertical viewing angles

- Multi-Enhancement: Many types of enhancement (like optical, electronic, computer assisted, multi-date, multi-band, multi-spectral) are available to the image analyst

- Multi-Disciplinary: Utilizing teams of interpreters with expertise in different disciplines, more information is obtained for a given application

- Multi-Thematic: Many different themes (e.g. hydrology, vegetation, transportation, urban areas, etc.) can be extracted from a single set of images

- Multi-Use: Many persons from different disciplines (e.g. environmental planners, resource managers, public policy decision makers) can use the output of an image interpretation

Methods of Search

Interpretation should

- Be conducted one step at a time

- Begin with the general and proceed to the specific

- Proceed from the known to the unknown

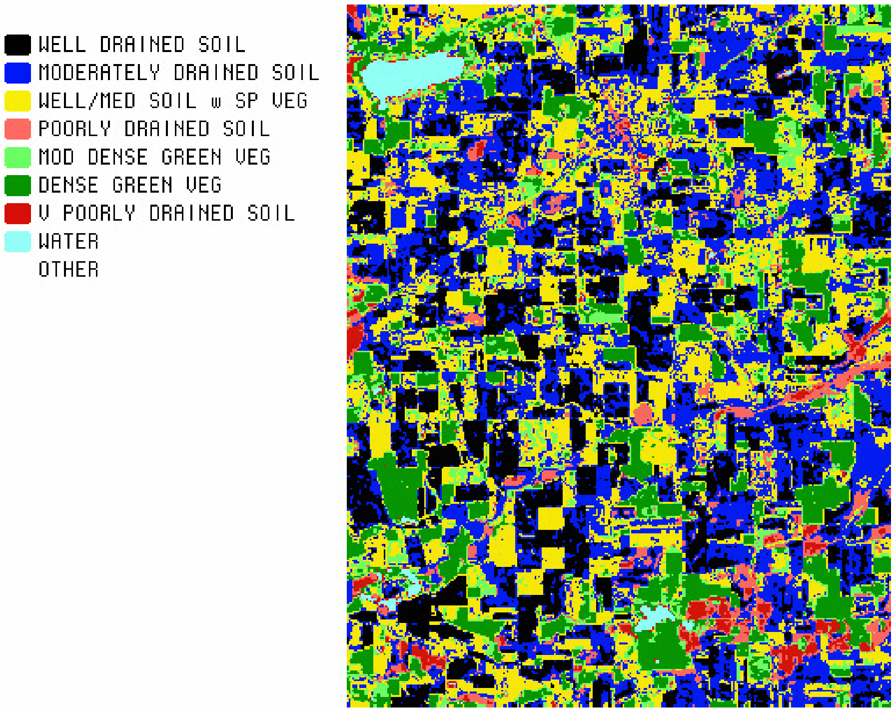
Conclusion and Accuracy of Image Interpretation Results

- Image interpretation is deductive, i.e. features that can be detected and identified lead the interpreter to the location and identification of other features

- Completeness and accuracy of image interpretation, to a certain extent, depend on the understanding of the interpreter on how and why to use certain elements, techniques and methods of interpretation. Overall, image interpretation results are subjective, however can yield practical and economical conclusions in certain dedicated applications.

10.3. CLASSIFICATION

SUPERVISED CLASSIFICATION: Classification schemes use a training area in the image from which a spectral signature is defined. For the spectral signature, the investigator has some prior knowledge. This spectral signature is then extrapolated throughout the image or to another image, to search for other spectrally similar areas. This is known as 'supervised classification'.



Assumptions made in the following classification:

i) The image to be processed is reduced in size to 49 picture elements (pixels), compared to the several millions typical of digital images

ii) Images have only two spectral bands (or dimensions in feature space) whereas a multispectral image may contain in the order of tens, hundreds or even thousands of spectral channels or bands. BAND-1 is red and BAND-2 is portion of the reflective infrared

iii) Number of intensity levels in the image is taken as 10 whereas this is typically 64 to 256 as recorded by a sensor

- A digitized image, 2 bands, 7 x 7 pixel area, line interleaved (first row of first band, first row of second band, second row of first band, ..etc. until seventh row of second band) is given in the below Figure-1

- Image intensity values are given below:

5	3	4	5	4	5	5	5	5	4	6	7	7	7	2	2	3	4	4	4	6	2	4

6	5	5	6	5	2	2	3	3	6	6	8	5	3	5	7	6	6	8	2	2	6	6

9	8	7	3	4	5	6	8	8	7	3	6	8	8	8	7	4	3	5	8	8	8	7

1	3	6	8	7	2	3	2	4	5	8	7	1	0	0	4	6	7	3	3	2	1	3

6	7	0	0	0	0

- Replace in the below Figure-2, the image intensities in Band-1 and Band-2 in the relevant pixels

BAND-1 (PIXELS × LINES)

LINES	1	2	3	4	5	6	7
1	**5**	**3**	**4**	**5**	**4**	**5**	**5**
2	**2**	**2**	**3**	**4**	**4**	**4**	**6**
3	**2**	**2**	**3**	**3**	**6**	**6**	**8**
4	**2**	**2**	**6**	**6**	**9**	**8**	**7**
5	**3**	**6**	**8**	**8**	**8**	**7**	**4**
6	**3**	**6**	**8**	**7**	**2**	**3**	**2**
7	**4**	**6**	**7**	**3**	**3**	**2**	**1**

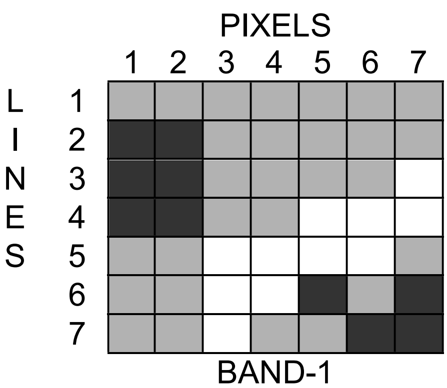
BAND-2 (PIXELS × LINES)

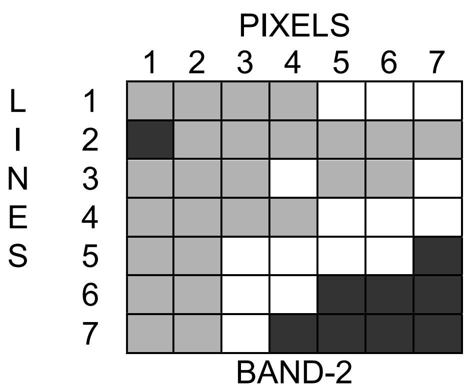
LINES	1	2	3	4	5	6	7
1	**5**	**5**	**4**	**6**	**7**	**7**	**7**
2	**2**	**4**	**6**	**5**	**5**	**6**	**5**
3	**5**	**3**	**5**	**7**	**6**	**6**	**8**
4	**3**	**4**	**5**	**6**	**8**	**8**	**7**
5	**3**	**5**	**8**	**8**	**8**	**7**	**1**
6	**4**	**5**	**8**	**7**	**1**	**0**	**0**
7	**3**	**6**	**7**	**0**	**0**	**0**	**0**

- For each of the BAND-1 and BAND-2 digital images in Figure-2, transform the numerical values of each pixel into a "shade" of grey according to the following conversion (for simplicity):

Numerical Value	0	1	2	3	4	5	6	7	8	9
Grey Level										

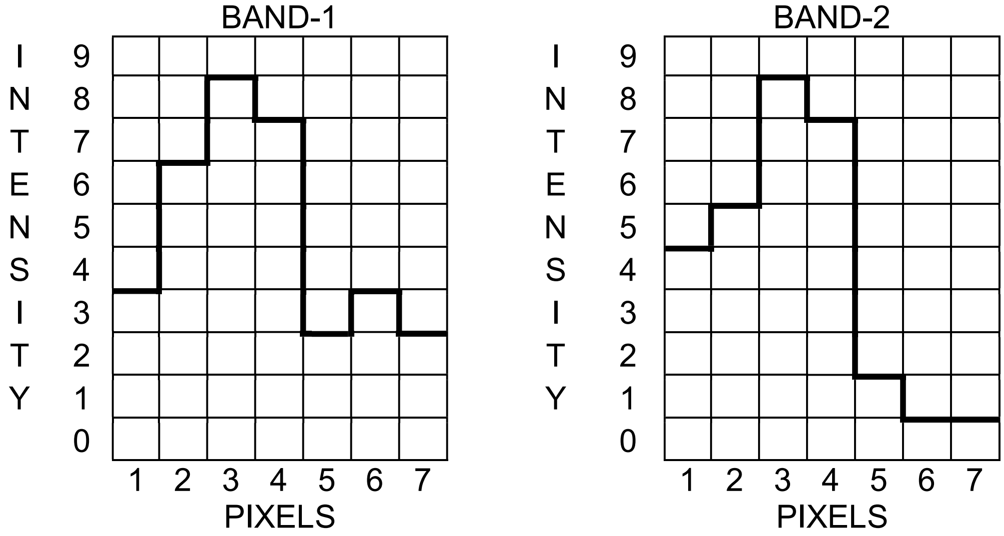
- Replace the above grey shades in Figure-2 and obtain the below Figure-3 Grey maps





- An ‘intensity profile’ gives a one-dimensional view of a single cross-section of the data

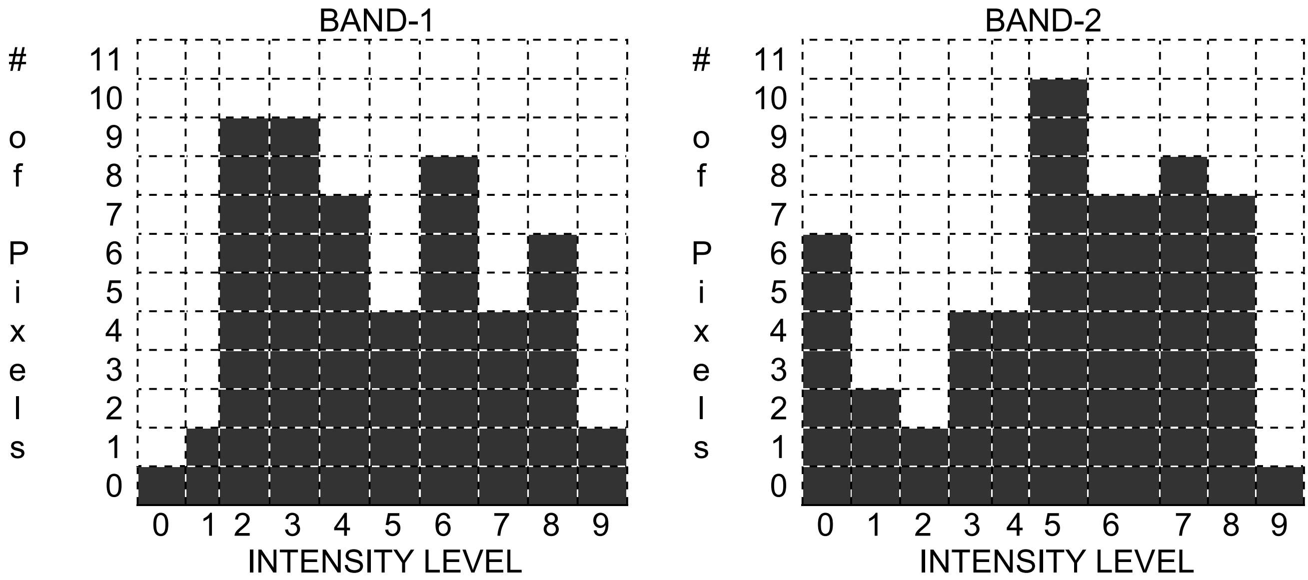
- For example construct an intensity profile for line number 6 of each of the BAND-1 and BAND-2 images. This is given in the below Figure-4



- One-dimensional histogram gives a graphical representation of the data distribution for a single BAND

- For BAND-1, count the number of pixels which have an intensity of zero. Use the digital image in Figure-2. Enter this number in the below Figure-5. Now count the number of times that the intensity level 1 occurs and similarly replace it on Figure-5. Continue for all levels. Check that the sum of these values is 49 (= 7 x 7). Similarly construct the histogram for BAND-2

- Below Figure-5 shows these one-dimensional histograms



Number of pixels:

0	**1**	**9**	**9**	**7**	**4**	**8**	**4**	**6**	**1**

Sum = **49**

Number of pixels:

6	**2**	**1**	**4**	**4**	**10**	**7**	**8**	**7**	**0**

Sum = **49**

- Several observations can be made from these two histograms:

  - Two histograms are significantly different meaning that there is <u>different information</u> in the two bands for the same pixel (or ground area)

  - Note the various peaks of the histograms. Each peak separated from neighbouring peaks by **valleys** is called a **'mode'** of the histogram.

  - Mode corresponds to a particular feature on the ground

  - Presence of several of these modes (a multi-modal histogram) leads to the conclusion that several (different) environmental features are imaged

  - Considering BAND-2 histogram, there are two major modes separated by the valley at intensity level 1

  - Since BAND-2 is reflective infrared band, knowledge of the infrared reflection characteristics of land and water can help to identify these two modes. Water strongly absorbs infrared, resulting in low reflectivity. Typically vegetation-covered land surfaces will have high reflection during the summer months. Thus, the assumption is made that the left peak or mode designates water while the large mode on the right is of the land surfaces. By counting the number of pixels in each mode, we already have an idea of the relative size of areas of land and water in the image, even though we haven't seen the image as yet

  - **'Spectral signature'** of any one pixel is the combination of its intensity levels in the two bands. This characteristic can be plotted in a two-dimensional (2-D) histogram

  - Plot the intensity coordinates for each pixel on the below Figure-6. Use the digital maps of Figure-2. When the intensity coordinates for a pixel are found in Figure-6, place a tick mark in the appropriate square.

Figure-6 Two-dimensional histogram.

BAND-2 Intensities										
9										
8									//////	/
7				/	/	//		/// /		
6				/	/	/	/// /			
5			/	//	//	/	/// /			
4			//	/	/					
3			//	/	/					
2			/							
1			/		/					
0		/	//	///						
	0	1	2	3	4	5	6	7	8	9

BAND-1 Intensities

- Sum these tick marks to find the total in all the pixels.
- 2-Dimensional histogram prepared in this manner in the below Figure-7 will show data distribution of both bands simultaneously.

Figure-7 Two-dimensional histogram.

BAND-2 Intensities

BAND-2 \ BAND-1	0	1	2	3	4	5	6	7	8	9
9										
8									**6**	**1**
7				**1**	**1**	**2**		**4**		
6				**1**	**1**	**1**	**4**			
5			**1**	**2**	**2**	**1**	**4**			
4			**2**	**1**	**1**					
3			**2**	**1**	**1**					
2			**1**							
1			**1**		**1**					
0		**1**	**2**	**3**						

BAND-1 Intensities

- Each 'square' or location in the completed 2-D histogram is called a **'cell'** or a **'vector'**
- **2-D histogram** plot is also the **spectral signature** domain
- **Cells which are close to each other in this plot have near-similar spectral characteristics**

CLASSIFICATION USING ONE BAND

- Figure-8 below represents a ground verification map for a particular environmental feature 'forest'

Figure-8 Ground verification map: 'Forest'.

PIXELS

LINES	1	2	3	4	5	6	7
1						**F**	
2					**F**		
3							
4	**F**						
5							
6							
7							

- 3 sites are identified on the ground as being forested terrain and the experts who collected this data are further assured that the combination of these three sites is representative of all forest types to be found in the area covered by the remotely sensed image

- Assume that the ground verification map has been geometrically registered to the image, so that the same point on the map and the image can be referenced by ‘line’ and ‘pixel’ coordinates

- By using the spectral signature of these **verified** ‘forest’ areas, one may find all other ‘forest’ pixels

- This is done by searching all pixels in the scene for similar spectral signatures

- First define the spectral characteristics of the given training sites

- Find the intensities corresponding to each of the 3 test sites for BAND-1

- The category or **class**, **‘forest’**, can be assumed to be characterized by the <u>range</u> of intensities found in BAND-1

- Range is defined by the minimum and maximum intensity values from these 3 samples

    - BAND-1 intensity values are 5 , 4 , 2

    - BAND-1 intensity range is minimum: 2 maximum: 5

- Repeat the process for BAND-2

    - BAND-2 intensity values are 7 , 5 , 3

    - BAND-2 intensity range is minimum: 3 maximum: 7

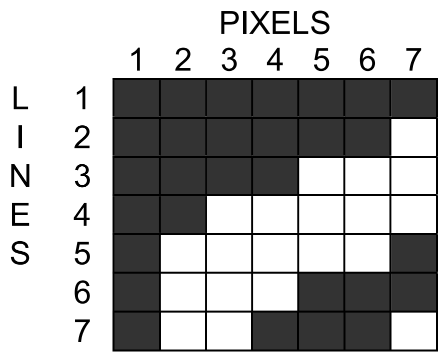
- Classification process now involves searching for all pixels which have an intensity level falling within the range of intensities found in the test sites

- The above is done separately for each band

- So using the BAND-1 digital image of Figure 2, **darken** all of the pixels in the image for intensities falling in the range defined for BAND-1 (i.e. intensities of 2, 3, 4, 5)

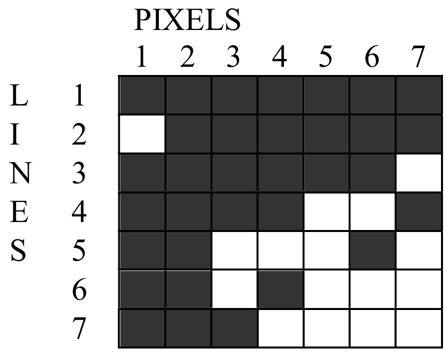
- Thus form the below Figure-9a

Figure-9a Forest map from BAND-1.



- Repeat the process using the BAND-2 digital image of Figure 2 (i.e. darken 3, 4, 5, 6, 7) and thus form the below Figure-9b

Figure-9b Forest map from BAND-2



- The two forest theme maps in Figure-9a and 9b represent the same environmental feature (= forest) but are different because each map was generated using information from one band only

- Procedure used to produce these theme maps is a form of **intensity 'slicing'**. i.e. one specific range of intensities was sliced from the total available range

- More correct classification can be produced if the intensities in both BANDS are considered simultaneously

MULTISPECTRAL CLASSIFICATION (RECTANGULAR)

- In order to classify an image in a multi-spectral (or multi-band) mode, the intensities in all BANDS must be considered simultaneously

- In Figure-l0a, the range of intensities in BAND-1 representing 'forest', is represented by the shaded area from BAND-1 intensity 2 to 5 inclusive

- Similarly in Figure-10a for BAND-2, 'forest' is represented by the shaded area of intensities 3 to 7 inclusive

- The overlap of these two individual intensity ranges in this two-dimensional diagram is a cross-hatched area representing the multispectral (rectangularly-defined) spectral signature of 'forest'

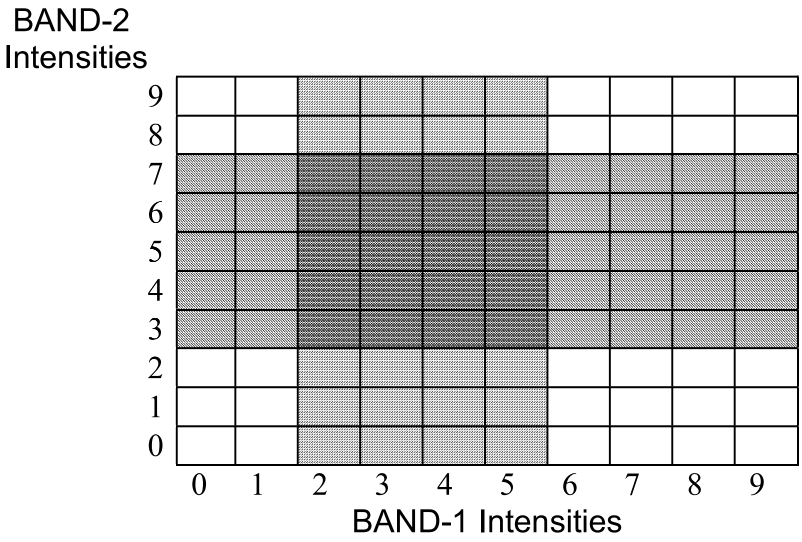
- In order to produce a multispectral classification of 'forest', it is necessary to find all pixels of the image whose spectral coordinates fall inside the cross-hatched rectangular area

- Using the digital images of Figure 2, scan all pixels for BAND-1 intensities of 2, 3, 4, or 5

- When a pixel has one of these BAND-1 intensities, check if its BAND-2 intensity is 3, 4, 5, 6 or 7

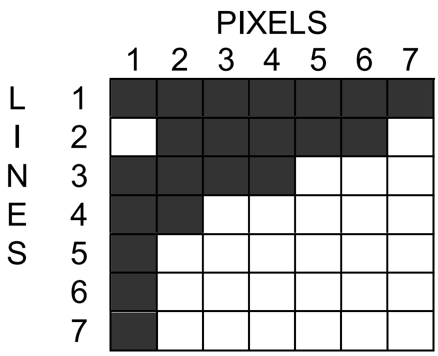
- If a pixel agrees with <u>both</u> of these criteria, then shade in the corresponding pixel in Figure-10b

Figure-10a   Feature space portion representing ‘Forest’.



- Forest map of below Figure-l0b is the logical overlap between forest maps 9a and 9b

Figure-10b   ‘Forest’ theme from BAND-1 and BAND-2



TO SUMMARIZE:

- Rectangular multispectral classification requires **‘representative samples’** of the environmental feature to be mapped

- Intensities of these sample pixels are collected in each band

- The <u>range</u> of intensities which correspond to the feature of interest is plotted as spectral band versus spectral band **(feature space)**

- The **rectangle** thus defined in two-dimensional feature space is the **spectral signature** of the environmental feature

- When more than two dimensions are used (e.g. hundreds of bands on airborne multispectral sensors) then N-bands can produce an N-dimensional **‘rectangular parallelepiped’ spectral signature**

MULTISPECTRAL CLASSIFICATION (VECTOR)

- Further refinement of the spectral signature, as defined by rectangular multispectral classification, is possible

- To illustrate this refinement, basic limitation of the rectangular classification technique is demonstrated below

- Forest map of Figure-l0b is verified on the ground by visual inspection and <u>homogeneous stands</u> of **C**oniferous and **D**eciduous forests are identified

- Below Figure-11a shows the spatial distribution of these two forest types

Figure-11a Ground verification map: 'Forest Types'.

LINES \ PIXELS	1	2	3	4	5	6	7
1	**D**			**D**	**D**	**D**	**D**
2		**C**				**D**	
3	**C**	**C**		**D**			
4	**C**	**C**					
5	**C**						
6	**C**						
7	**C**						

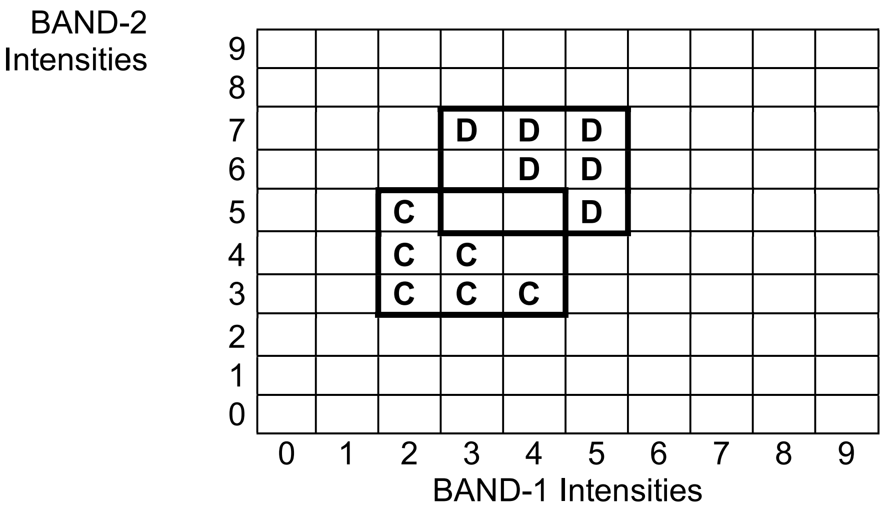
where **'C'** = **C**oniferous and '**D**' = **D**eciduous

- In order to delineate the portions of spectral feature space which correspond to each of the two forest types:

  - For each pixel identified in the ground verification map of Figure-11a, find the corresponding BAND-1 and BAND-2 intensities in Figure 2

  - Plot each such spectral coordinate in the below Figure-11b using symbols **'C'** (**C**oniferous) and **'D'** (**D**eciduous)

Figure-11b Forest type designation in feature space.



- Draw a rectangle to define the spectral signature of ‘**C**oniferous forest’
- Two vertical sides of this rectangle are the lower and upper limits of the range of intensities for BAND-1
- Top and bottom lines of the rectangle are the upper and lower limits of the range of intensities for BAND-2
- Draw a similar rectangle for the spectral signature of ‘**D**eciduous forest’
- Note that the two rectangles **partially overlap**

- It is this overlapping of spectral signatures in feature space which is a major **limiting factor to the usefulness of the rectangular classification** method
- If a particular pixel has spectral coordinates which fall into the overlap region, then one is at a loss whether to label this pixel as ‘**C**oniferous’ or ‘**D**eciduous’
- **Multispectral vector classifier** looks inside any feature space rectangle to identify <u>each</u> spectral coordinate (also known as "cell" or ‘vector’) and the number of pixels which are associated with each coordinate
- This defines the **data density distribution in feature space**
- Use a multispectral vector classification scheme to map coniferous and deciduous forests in <u>**another scene**</u>
- First scene is used in Figure-11a and 11b to ‘train’ the classifier
- İ.e: First scene contains the test sites from which the spectral signatures of the two forest types are defined
- These spectral signatures can be extrapolated to another area (scene No. 2) to look for similar environmental features
- Figures-12a and 12b below contain the digital images of BAND-1 and BAND-2 of the new scene (No. 2)
- Figure-12c is the feature space representation of the spectral signatures of **C**oniferous (**C**) and **D**eciduous (**D**) forests
- Scan the new scene pixel by pixel
- In order to classify any one pixel as one of the two forest types, it must agree in BAND-1 and BAND-2 intensities with one of the cells in Figure-12c, which is marked ‘**C**’ or ‘**D**’
- It is <u>**NOT**</u> sufficient for the spectral coordinates to merely fall within the rectangular limits
- It is mandatory that the spectral coordinates being considered coincide with a cell marked by ‘**C**’ or ‘**D**’

- Only in this manner will ambiguities related to the overlap region be avoided

- Those pixels thus identified in Figure-12c should be marked appropriately as '**C**' or '**D**' on the theme map of Figure-12d

Shown below is Figure-12a Scene #2, BAND-1.

PIXELS

LINES		1	2	3	4	5	6	7
L	1	**3**	**4**	**1**	**1**	**2**	**2**	**2**
I	2	**4**	**4**	**4**	**2**	**1**	**2**	**2**
N	3	**3**	**3**	**5**	**2**	**2**	**2**	**2**
E	4	**5**	**5**	**2**	**2**	**2**	**2**	**2**
S	5	**4**	**5**	**5**	**2**	**2**	**2**	**2**
	6	**4**	**3**	**3**	**4**	**4**	**5**	**5**
	7	**5**	**5**	**3**	**4**	**4**	**5**	**4**

Shown below is Figure-12b Scene #2, BAND-2.

PIXELS

LINES		1	2	3	4	5	6	7
L	1	**7**	**7**	**0**	**0**	**0**	**3**	**3**
I	2	**7**	**7**	**6**	**0**	**0**	**3**	**4**
N	3	**4**	**4**	**7**	**1**	**1**	**3**	**4**
E	4	**7**	**7**	**4**	**4**	**3**	**4**	**4**
S	5	**6**	**7**	**7**	**4**	**5**	**5**	**5**
	6	**7**	**5**	**5**	**5**	**7**	**7**	**6**
	7	**7**	**6**	**6**	**7**	**7**	**7**	**7**

Shown below is Figure-12c Scene #2, feature space

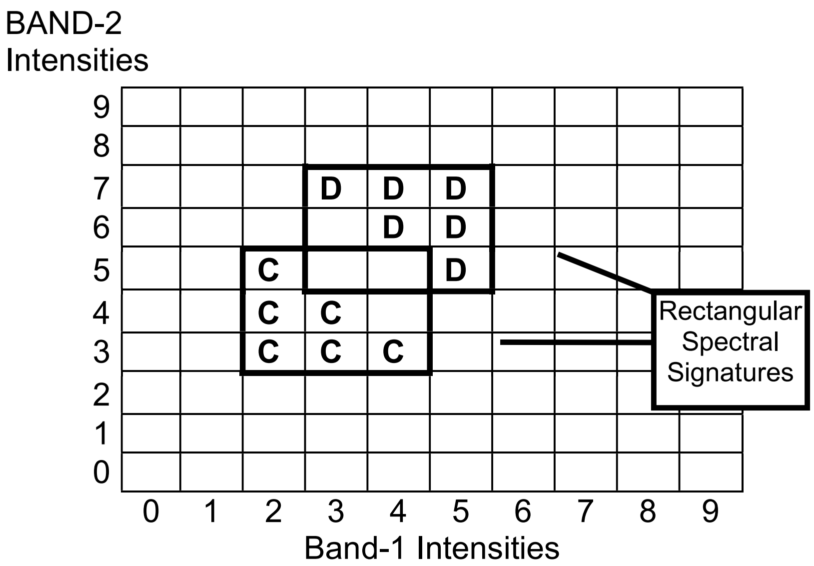


Figure-12d   Scene #2, theme map

		PIXELS 1	2	3	4	5	6	7
L	1	**D**	**D**				**C**	**C**
I	2	**D**	**D**	**D**			**C**	**C**
N	3	**C**	**C**	**D**			**C**	**C**
E	4	**D**	**D**	**C**	**C**	**C**	**C**	**C**
S	5	**D**	**D**	**D**	**C**	**C**	**C**	**C**
	6	**D**				**D**	**D**	**D**
	7	**D**	**D**		**D**	**D**	**D**	**D**

'C' = Coniferous Forest
'**D'** = Deciduous Forest

- The above procedure is called: '**N-dimensional training**', to refer to the fact that the intensities of **more than one band** are considered simultaneously

- This type of training and classification scheme is also known as '**non-parametric'** in that the **absolute location of spectral coordinates** in feature space is the criterion for defining an environmental feature, and **NOT statistical parameters** such as mean and standard deviation

INTERPRETATIONS FROM SPECTRAL SIGNATURES

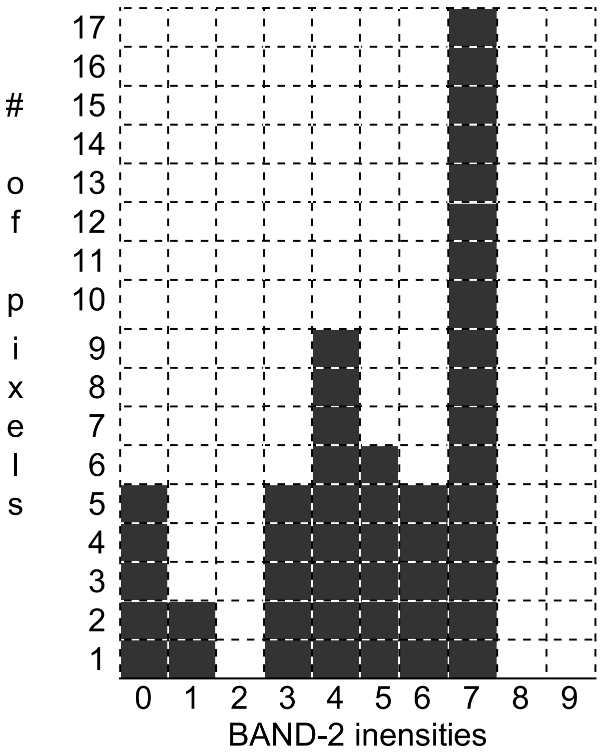
- Ground verification is essential in assigning environmentally valid names to features found on an image

- However, it is appropriate to make deductions concerning an unverified feature, from its spatial and spectral characteristics

- As studied before, one-dimensional histogram of the infrared BAND-2 displays a marked difference between a low intensity mode corresponding to water and a high intensity mode corresponding to land features

- This can be observed on the one-dimensional histogram of BAND-2 of **scene No. 2**, plotted in below Figure-13a

FIGURE-13a Scene #2, BAND-2, one-dimensional histogram.



- The left mode of the histogram comprising BAND-2 intensities less than 2 will relate to water pixels to a high degree of certainty

- The major conflicting phenomenon would be shadow areas due to clouds or mountains which would also result in low intensities

- Find those pixels in Figure-12b which have intensities less than 2 and mark the corresponding pixels in Figure-12d as **W**ater: **'W'**. This is shown below:

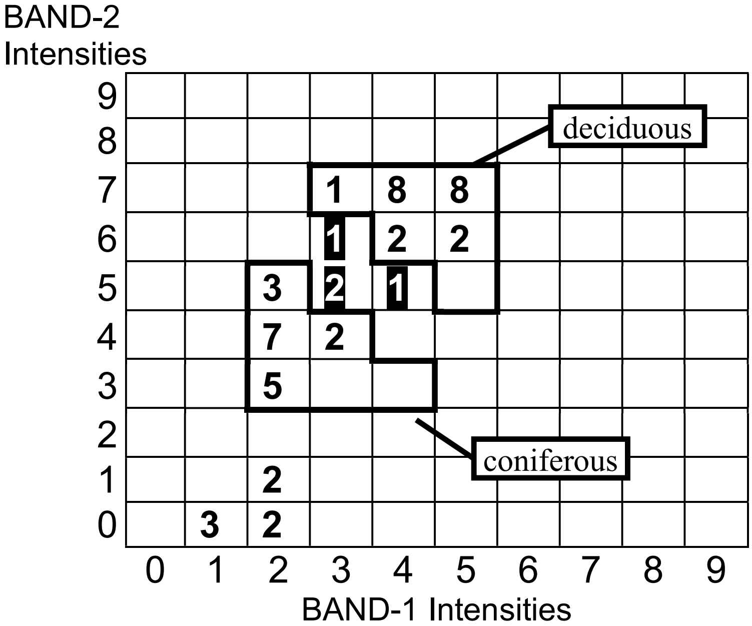
Figure-12d with **'W'** added

		PIXELS						
		1	2	3	4	5	6	7
L	1	**D**	**D**	**W**	**W**	**W**	**C**	**C**
I	2	**D**	**D**	**D**	**W**	**W**	**C**	**C**
N	3	**C**	**C**	**D**	**W**	**W**	**C**	**C**
E	4	**D**	**D**	**C**	**C**	**C**	**C**	**C**
S	5	**D**	**D**	**D**	**C**	**C**	**C**	**C**
	6	**D**				**D**	**D**	**D**
	7	**D**	**D**		**D**	**D**	**D**	**D**

'W': Water:

- Portions of feature space which were previously defined as representing coniferous and deciduous forest are indicated in the below Figure 13b

Figure-13b Scene #2, two-dimensional histogram



- It is reasonable to assume that the portion of feature space which lies <u>between</u> two specific spectral signatures, may represent a <u>mixed</u> environmental target

- Thus, the cells lying between the areas shown as 'coniferous' and 'deciduous' may be the spectral representation of the mixture of these two forest types, namely mixedwood

- Identify the pixels which are represented by these cells which may be mixedwood (there are 3 of these cells marked as black in Figure-13-b)

- Mark these cells on Figure-12d as **'M'** denoting **M**ixedwood

- Verify that the correct number of pixels have been identified as mixedwood by summing the frequencies of occurrance of the intensity levels of the three cells in Figure-13b (1 + 2 + 1 = 4 each of **'M'** should be marked. This is shown below:

Figure-12d with **'M'** added

LINES	PIXELS 1	2	3	4	5	6	7
1	**D**	**D**	**W**	**W**	**W**	**C**	**C**
2	**D**	**D**	**D**	**W**	**W**	**C**	**C**
3	**C**	**C**	**D**	**W**	**W**	**C**	**C**
4	**D**	**D**	**C**	**C**	**C**	**C**	**C**
5	**D**	**D**	**D**	**C**	**C**	**C**	**C**
6	**D**	**M**	**M**	**M**	**D**	**D**	**D**
7	**D**	**D**	**M**	**D**	**D**	**D**	**D**

'M'= Mixedwood

UNSUPERVISED CLASSIFICATION

- Previous classification schemes used a training area in the image from which a spectral signature was defined and for which the investigator had some prior knowledge

- This spectral signature is then extrapolated throughout the image or to another image by searching spectrally similar areas

- This is known as a variation of ‘supervised classification’

- Sometimes, it is preferred to **reverse the procedure**

- It is sometimes useful to delineate spectrally dissimilar areas of an image even when nothing is known about the environmental character of the resulting subdivisions or classes

- These classes are then mapped and the map taken into the field to identify the classes

- This procedure is known as ‘**unsupervised classification’** since no training sites are involved

- Main advantage unsupervised classification is that the classes are subdivided based on their **statistical** characteristics usually covering **large** geographical areas, rather than depending on a ‘training sample’ which may be quite unrepresentative of the class variability over the whole scene to be mapped

- An algorithm will be used below that relies on finding areas of high pixel density (in feature space) which are separated by regions of low density

- The feature space representation (Figure-13b) of scene No. 2 is reproduced in the below Figure-14a

Figure-14a Scene #2, feature space

BAND-2 Intensities

9										
8										
7				**1**	**8**	**8**				
6				**1**	**2**	**2**				
5			**3**	**2**	**1**					
4			**7**	**2**						
3			**5**							
2										
1			**2**							
0		**3**	**2**							
	0	1	2	3	4	5	6	7	8	9

BAND-1 Intensities

- Copy those cells from Figure-14a, which have a count of (density) 3 or more Into the below Figure-14b

Figure-14b Scene #2, feature space with count of (density) 3 or more

BAND-2
Intensities

9										
8										
7					**8**	**8**				
6										
5			**3**							
4			**7**							
3			**5**							
2										
1										
0		**3**								
	0	1	2	3	4	5	6	7	8	9

BAND-1 Intensities

- 3 clusters of high density cells are observed in the above Figure-14b (Scene #2, feature space with count of (density) 3 or more)

- These groupings of high density cells are each only the nucleus of a cluster

- Next step is to define the boundaries of each whole cluster

- Cluster with a nucleus of two cells will be called **cluster 'A'** in feature space and **class 'A'** when it is finally mapped geographically (by line and pixel)

- Identify each cell which touches the nucleus cells of cluster 'A', by marking such cells with the letter 'A'

- There should be I0 such cells marked, counting even those cells which touch with a corner only. This is shown below:

BAND-2
Intensities

9										
8				**A**	**A**	**A**	**A**			
7				**A**	**8**	**8**	**A**			
6				**A**	**A**	**A**	**A**			
5			**3**							
4			**7**							
3			**5**							
2										
1										
0		**3**								
	0	1	2	3	4	5	6	7	8	9

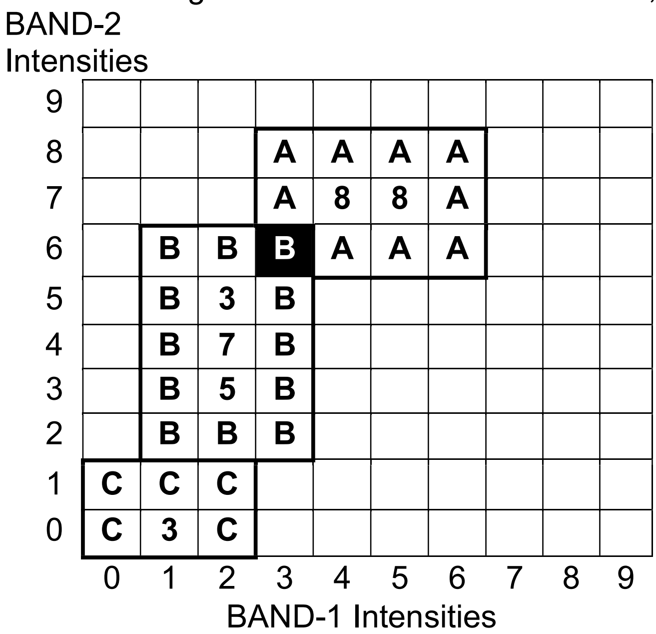
BAND-1 Intensities

- Repeat the process for cluster ‘B’ (with three nucleus cells) using the letter ‘B’ for the neighbouring cells, and also for cluster ‘C’ (with one nucleus cell) and using the letter ‘C’

- There will be a point of ambiguity where two clusters overlap and a cell (dark cell in the below Figure-14b) is identified as belonging to the neighbourhood of two clusters

- A decision must be forced, so identify this conflict cell (dark cell in the below Figure-14b) as belonging to the cluster with the <u>larger</u> nucleus

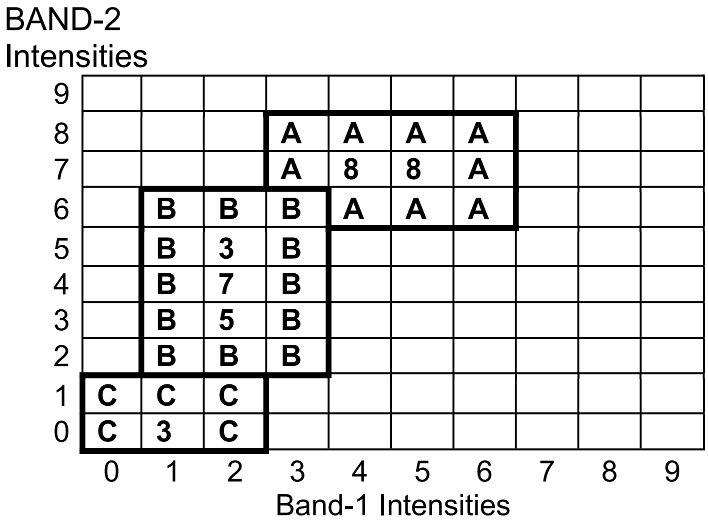
Figure-14b with all the clusters ‘A’ , ‘B’ and ‘C’



- Draw the boundary for <u>each</u> cluster enclosing its complete neighbourhood in Figure-14b

- There are 11 cells inside the boundary for cluster ‘A’, 15 cells in cluster ‘B’ and 6 cells in cluster ‘C’. This is shown in the below Figure-14b (Scene #2, feature space with boundaries) Transfer just the boundaries back to the original feature space in Figure-14a

Figure-14b Scene #2, feature space with boundaries



- Transfer those cells in Figure-14a, which fall inside the boundary for cluster 'A' and which display a count or density of 1 or greater, into the below Figure-14c, and identify those cells by the letter 'A'

- Repeat the procedure for clusters 'B' and 'C' using the appropriate designation

Figure-14c Scene #2, feature space showing the clusters

BAND-2 Intensities	0	1	2	3	4	5	6	7	8	9
9										
8										
7				A	A	A				
6				B	A	A				
5			B	B						
4			B	B						
3			B							
2										
1			C							
0		C	C							

BAND-1 Intensities

- Next step is to map these clusters into their geographical locations

- For each pixel, spectral coordinates of Figure-14d are obtained from the digital maps of Figures-12a and 12b

- These coordinates are located in Figure-14c and the classification symbol (A, B, or C) are allocated to the relevant pixel in the below Figure-14d

Figure-14d Scene #2, unsupervised classification

PIXELS

LINES	1	2	3	4	5	6	7	
1	**A**	**A**	**C**	**C**	**C**	**B**	**B**	
2	**A**	**A**	**A**	**C**	**C**	**B**	**B**	
3	**B**	**B**	**A**	**C**	**C**	**B**	**B**	*
4	**A**	**A**	**B**	**B**	**B**	**B**	**B**	
5	**A**	**A**	**A**	**B**	**B**	**B**	**B**	
6	**A**	**B**	**B**		**A**	**A**	**A**	
7	**A**	**A**	**B**	**A**	**A**	**A**	**A**	

- It is required that the individual classes (A, B, C) of unsupervised classification shown in Figure-14d are identified environmentally

- Identification can be done in various ways: airphoto interpretation or actually visiting the site, if practical

- However, it is not necessary to completely cover the relevant scene

- Another advantage of the unsupervised classification scheme is that it can direct fieldwork or other forms of ground verification, to convenient, small and representative locations, where environmentally valid names may be assigned to the classes

- E.g. the location marked by an asterisk in Figure 14D would be a suitable location to identify classes 'A', 'B', and 'C' because of their proximity to each other

- Just a few such locations need to be investigated for a large scene, in order to be able to name the classes with confidence

- Also, during ground verification, those areas which are 'unclassified' (such as pixel No. 4, line No. 6 on Figure-14d) can be identified

- These unclassified areas can also be due to imperfections in the processing technique or a 'noisy' image

IMAGE ENHANCEMENT

- Image enhancement techniques make an image easier to analyze and interpret

- A common problem in remote sensing is that the range of reflectance values collected by a sensor may not match the capabilities of the display device

<u>Image Reduction</u>

- It is often necessary to locate the exact row and column coordinates of a study area within an image

- Many digital image processing systems are unable to display a full image at the normal commercial pixel scale (>3000 rows and 3000 columns)

- This brings can a problem in locating the exact coordinates of a study area

- Under such circumstances, image reduction allows the analyst to view a subset of an image at one time on the screen by reducing the original image dataset down to a smaller dataset

- Image reduction is useful for orientation purposes as well as fixing the exact row and column coordinates of an area of interest

- Digital image is reduced to $1/m^2$ of the original data if every other m^{th} row and every other m^{th} column of the image are selected

- E.g: if m=2 then the reduction will create a sampled image which consists only 25% of the pixels found in the original scene

- Reduction by m=2 is shown in the below Figure

Image Reduction

RAW IMAGE

1	67	33	45	72
8	16	54	34	38
40	35	65	68	70
36	56	49	29	37
38	39	51	38	35

REDUCED IMAGE

1	33	72
40	65	70
38	51	35

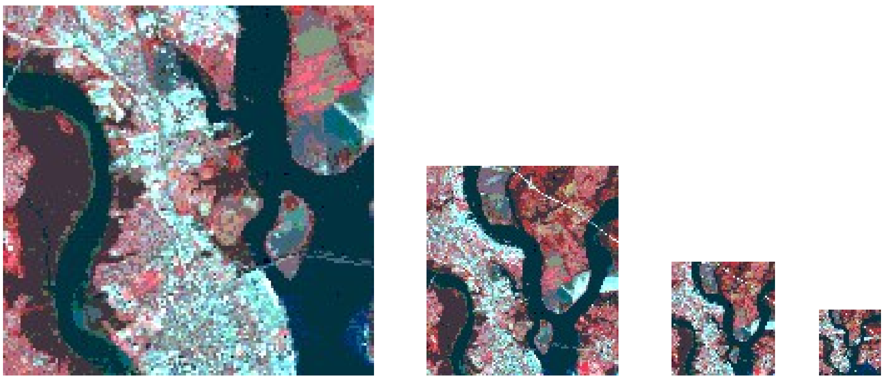
- An image sampled at a 10x reduction, i.e. every 10th row and 10th column of the image is sampled, will yield a resampled image containing only 1% of the original data and at this scale only the new image will be small enough to view the entire scene on the screen

- Because a resampled image looses many of its original pixels, it does not contain adequate data for image processing and interpretation

- Reduced images are usually used for orienting within a scene and locating the exact row and column coordinates of a specific study area

- These coordinates can then be used to extract a portion of the image for full resolution analysis

- Below Figure shows 1x, 2x, and 4x reduction of portion of a Landsat TM data



Unreduced image　　Reduced at 1x　　2x　　4x

Image Magnification

- Digital image magnification is known as zooming

- Image magnification is used for:

- Improving the scale of the image for enhanced visual interpretation
- Matching the scale of another image

- Row and column replication represent the simplest form of image magnification

- For magnifying an image by an integer factor m^2, each pixel in the original image is replaced by an mxm block of pixels which all have the equivalent brightness values as the original input pixels

- 2x magnification is shown in the below Figure.

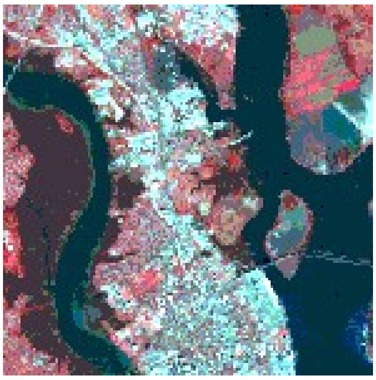
Raw Image

42	33	45
67	39	26
56	18	42

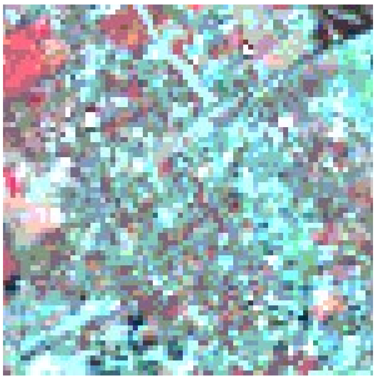
Image Magnification

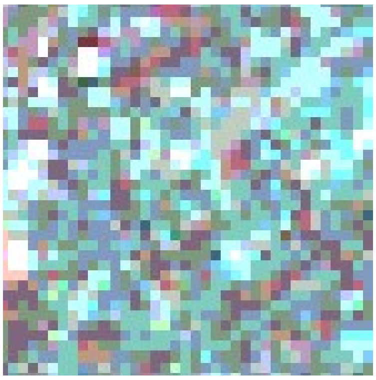
42	42	33	33	45	45
42	42	33	33	45	45
67	67	39	39	26	26
67	67	39	39	26	26
56	56	18	18	42	42
56	56	18	18	42	42

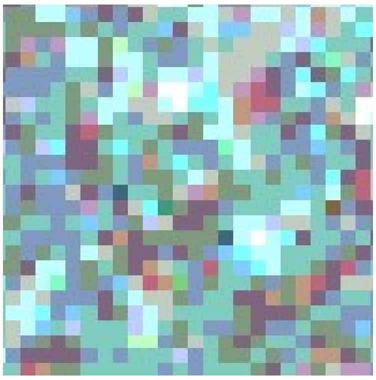
- Below Figure shows a Landsat TM data magnified 1x, 2x, 3x, 4x, and 8x.

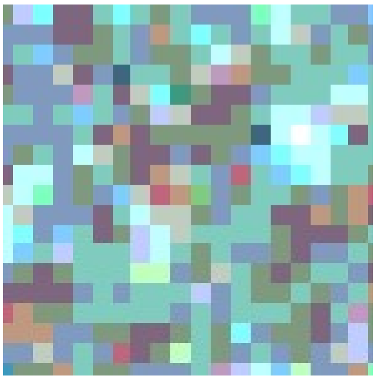

Initial TM data


Magnified at 1x


Magnified at 2x


Magnified at 3x

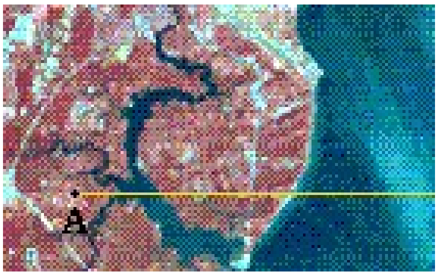

Magnified at 4x


Magnified at 8x

Transects

- Transect is a straight line between any two user-specified points within an image

- Pixels that lie on the transect can be measured and displayed to compare spectral or spatial differences



- The Brightness Profiles that occur between points A and B can be obtained for different bands

- İ.e plots where x-axis being the distance in pixels and the y-axis being the brightness values of the pixels along the transectixel value

- Each such graph contains a unique distribution per band

- Such a study is important in determining optimal bands for further analysis

- Image analysts use several transects in a single image to determine environmental trends or patterns

Contrast Enhancement

- A common problem in remote sensing is that the range of reflectance values collected by a sensor may not match the capabilities of the film or color display monitor

- Materials on the Earth's surface reflect and emit different amounts of energy

- A sensor may record a tremendous amount of energy from a one material in a certain wavelength, while another material is recorded at much less energy in the same wavelength

- Values present on an image is referred to as contrast

- Contrast enhancement is a process that makes the image features appear more clearly by making optimal use of the colors available on the display

- Contrast manipulations involve changing the range of values in an image in order to increase contrast

- E.g., an image might start with a range of values between 40 and 90. When this is stretched to a range of 0 to 255, the differences between features are emphasized

Linear Contrast Enhancement (or Contrast Stretching)

- Linear contrast enhancement linearly expands the original digital values of the remotely sensed data into a new distribution

- By expanding the original input values of the image, the total range of sensitivity of the display device can be utilized

- Linear contrast enhancement also makes subtle variations within the data more obvious

- Linear contrast enhancement is best applied to remotely sensed images with Gaussian or near-Gaussian histograms

- Gaussian histogram means all the brightness values fall within a narrow range of the histogram and only one mode is apparent

- There exists 3 methods of linear contrast enhancement:

    - Minimum-Maximum Linear Contrast Stretch
    - Percentage Linear Contrast Stretch
    - Piecewise Linear Contrast Stretch

Minimum-Maximum Linear Contrast Stretch

- When using the minimum-maximum linear contrast stretch, the original minimum and maximum values of the data are assigned to a newly specified set of values that utilize the full range of available brightness values

- Brightness After Stretch = (Brightness Before Stretch – Min. Brightness Before Stretch)/(Max. Brightness Before Stretch-Min. Brightness Before Stretch) x (Maximum Brightness Value After Stretch)

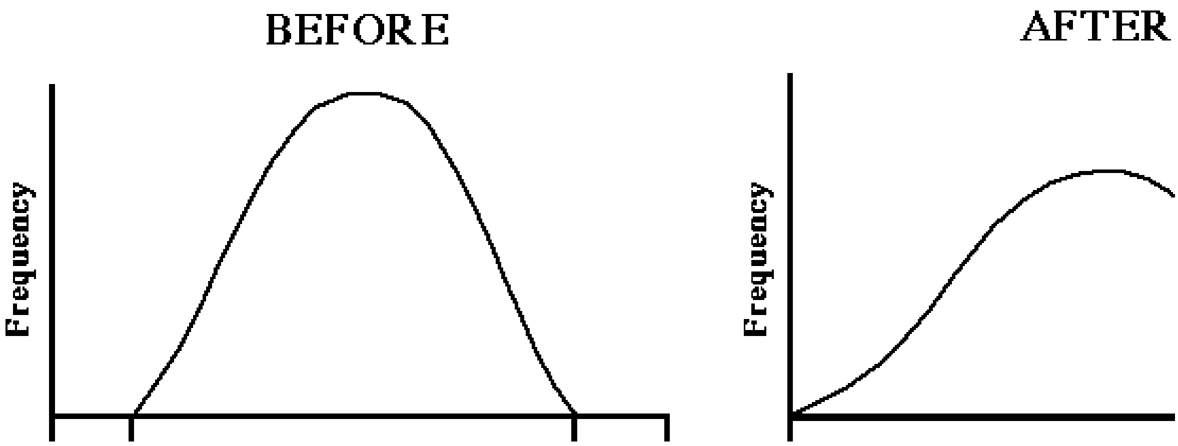
- E.g. An 8 bit resolution image (i.e. 256 Brightness Levels) image has a minimum brightness value of 45 and a maximum value of 205

- When such an image is viewed without enhancements, the values of 0 to 44 and 206 to 255 are not displayed

- Important spectral differences can be detected by stretching the minimum value of 45 to 0 and the maximum value of 206 to 255 by applying the above linear relationship

- E.g. Brightness of (45) After Stretch = (45-45)/(205-45)x255=0, Brightness of (205) After Stretch = (205-45)/(205-45)x255=255, Brightness of (145) After Stretch = (145-45)/(205-45)x255=160

- Below figure shows Minimum-Maximum Linear Contrast Stretch



- An algorithm can be used that matches the old minimum value to the new minimum value, and the old maximum value to the new maximum value

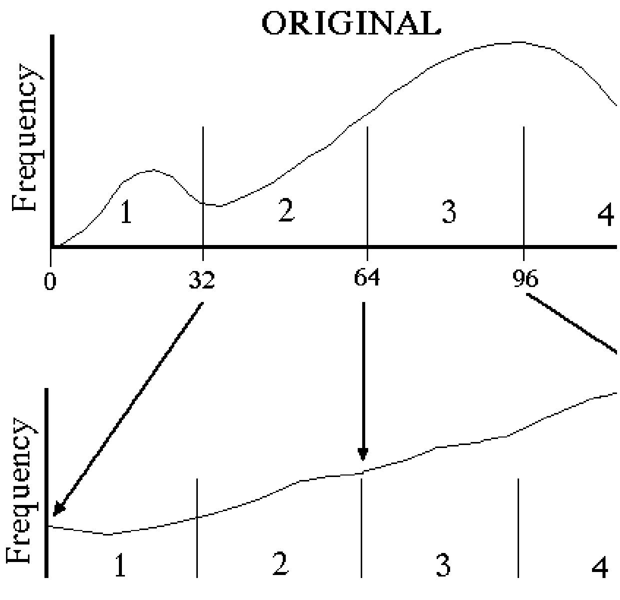
- All the old intermediate values are scaled proportionately between the new minimum and maximum values

- Many digital image processing systems have built-in capabilities that automatically expand the minimum and maximum values to optimize the full range of available brightness values

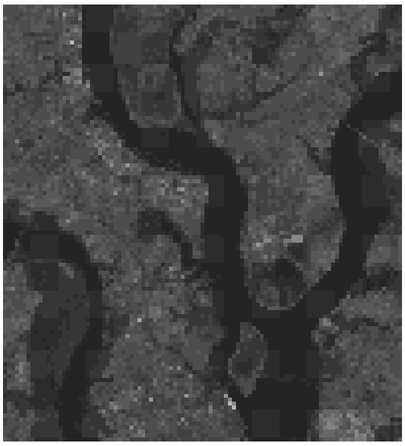
Percentage Linear Contrast Stretch

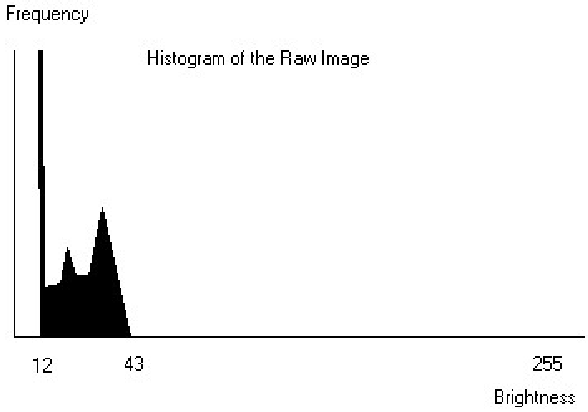
- The percentage linear contrast stretch is similar to the minimum-maximum linear contrast stretch except that the percentage linear contrast stretch method uses specified minimum and maximum values that lie in a certain percentage of pixels from the mean of the histogram

- Below Figure shows the approach used in a percentage linear contrast stretch



- Below Figures contains TM images and their associated histograms

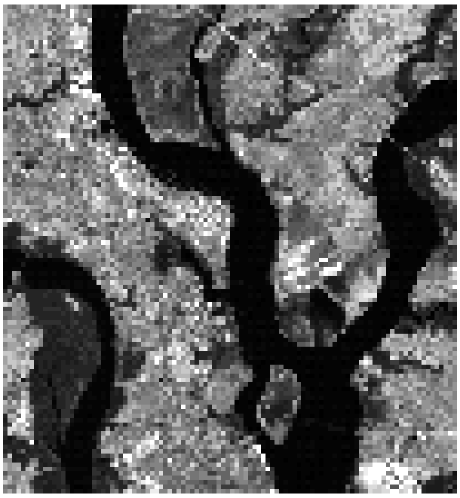


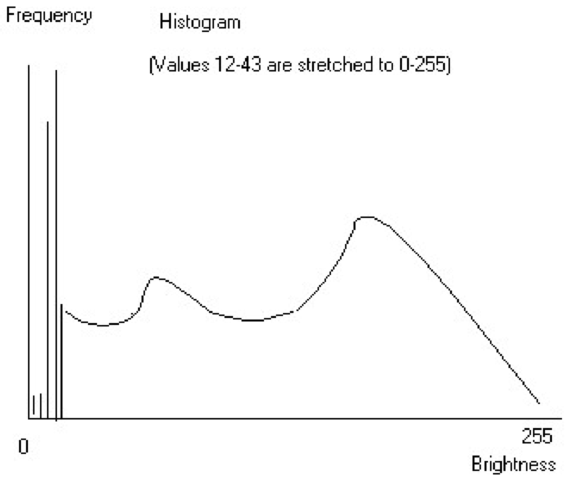


- First image below (Raw Data) displays the low-contrasting data in band 4 under normal conditions with no contrast stretch. The minimum brightness value is 12 and the maximum value 43

- Histogram shows how the data is densely clustered between these values

- In the second image (Stretch 1) below all values between 12 and 43 are linearly stretched using a minimum-maximum linear contrast stretch so that these values now lie within the range of 0 to 255



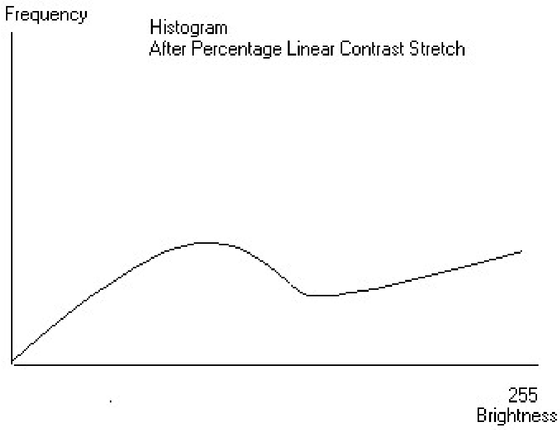


- Minimum value 12 becomes 0 and the maximum value 43 stretches to 255

- Histogram associated with this image demonstrates a wider distribution than the first histogram

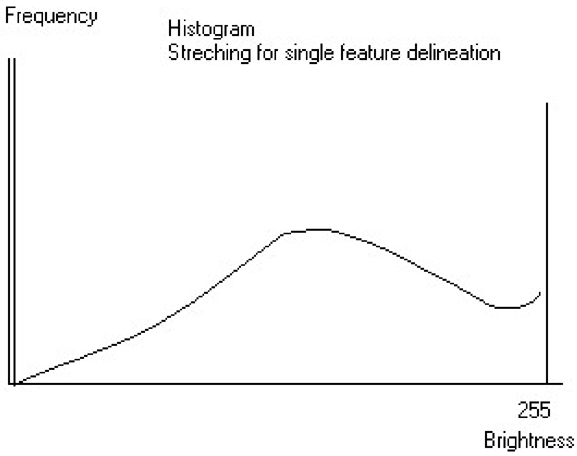
- This results in a pure pixel contrast that optimizes the capabilities of the display device

- Below third image (Stretch 2) continues to stretch the data by applying percentage linear contrast stretch



- Information content of the pixels that saturate at 0 and 255 is lost, yet a more detailed analysis of certain aspects of the image may be enhanced for better interpretation

- Below fourth image (Stretch 3) shows how an analyst would enhance an image if only interested in delineating single feature(e.g. wetlands)



- When the values between 13 and 27 are linearly stretched to 0 and 255, all values below 13 become 0 (black) and all values above 27 are set to 255 (white)

- This enhancement yields additional information on the smooth cordgrass at the expense at of the rest of the water and upland cover

- Image analysts often need to increase the contrast of an image only at specific portions of the electromagnetic spectrum

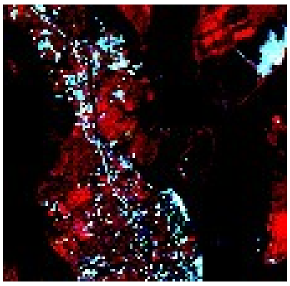
- E.g. an analyst who wants to extract detailed marine information in an image may only be interested in values between 0 and 12

- When these values are stretched to 0 and 255, subtle ocean variations can be more easily detected (see below Figure)

Image without Enhancements
TM Bands 4,3, and 2

Enhanced Image for Ocean Contrast
Red 0-10 Green 0-12 Blue 0-12

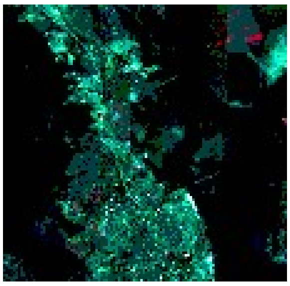
- A percentage stretch of the same image between values of 25 and 45 yields detailed vegetation information (see below Figure)



Enhanced for Vegetation Contrast
Red 25-45 Green 30-35 Blue 25-30

- This may be useful in the delineation of healthy vegetation

- If an analyst is interested in image enhancement for urban features, a percentage linear stretch between the values 40 and 70 in the red and 15 to 45 in the green and blue will increase the contrast of these features (see below Figure)



Enhanced for Urban Contrast
Red 40-70 Green 15-45 Blue 15-45

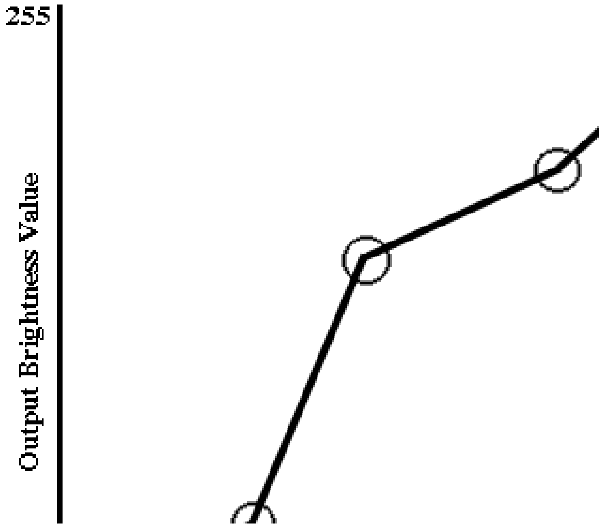
Piecewise Linear Contrast Stretch

- When the distribution of a histogram in an image is **bi or trimodal**, an analyst may stretch certain values of the histogram for increased enhancement in selected areas

- This method of contrast enhancement is called piecewise linear contrast stretch

- Piecewise linear contrast enhancement involves the identification of a number of linear enhancement steps that expands the brightness ranges in the modes of the histogram

- Below Figure shows piecewise linear contrast stretch output-input function



- In the piecewise stretch, a series of small min-max stretches are set up within a single histogram

- Piecewise linear contrast stretch is a very powerful enhancement procedure, however image interpreter must be very familar with the modes of the histogram and the features they represent in the real world

Nonlinear Contrast Enhancement

- Often involves histogram equalizations using a certain algorithm

- Nonlinear contrast stretch method has one major disadvantage that each value in the input image can have several values in the output image, so that objects in the original scene lose their correct relative brightness values

Histogram Equalization

- Histogram equalization is one of the most useful forms of nonlinear contrast enhancement

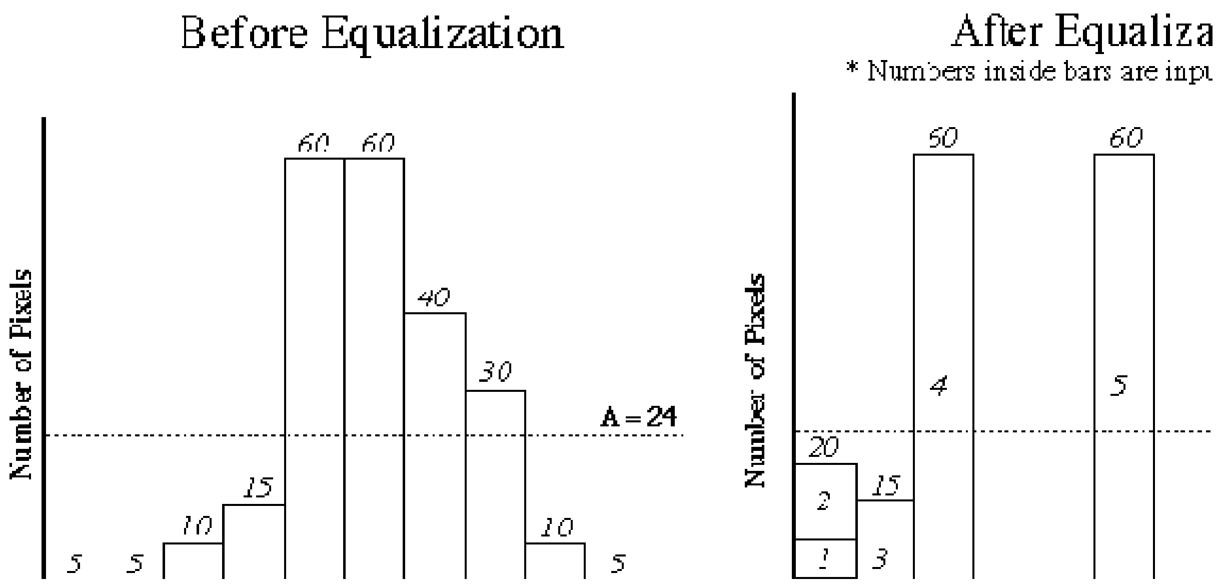
- When an image's histogram is equalized, all pixel values of the image are redistributed so there are approximately an equal number of pixels to each of the user-specified output gray-scale classes (e.g., 32, 64, and 256)

- When Histogram Equalization is applied, contrast is increased at the most populated range of brightness values of the histogram (or "peaks")

- Histogram Equalization automatically reduces the contrast in very light or dark parts of the image associated with the tails of a normally distributed histogram

- Histogram equalization can also seperate pixels into distinct groups, if there are few output values over a wide range

- Below Figure shows two histograms



- The first histogram shows values before equalization is performed

- When this histogram is compared to the equalized histogram, one can see that the enhanced image gains contrast in the most populated areas of the original histogram

- In this example, input range of 3 to 7 is stretched to the range of 1 to 8

- However, the data values at the tails of the original histogram are grouped together

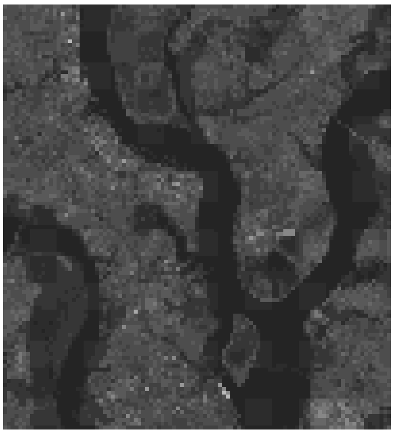
- Input values 0 through 2 all have the output values of 0

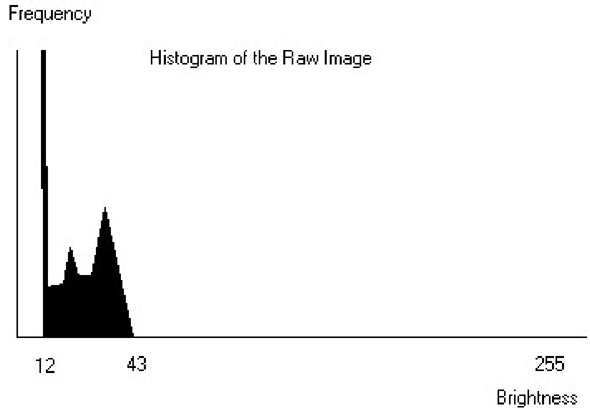
- This results in the loss of the dark and bright characteristics usually associated with the tail pixels

- Image analysts must be aware that while histogram equalization often provides an image with the most contrast of any enhancement technique, it may hide much needed information

- Histogram Equalization groups pixels that are very dark or very bright into very few gray scales

- In the below Figures notice the change in each of the histograms as values in the tails are grouped together.





Equalized Histogram

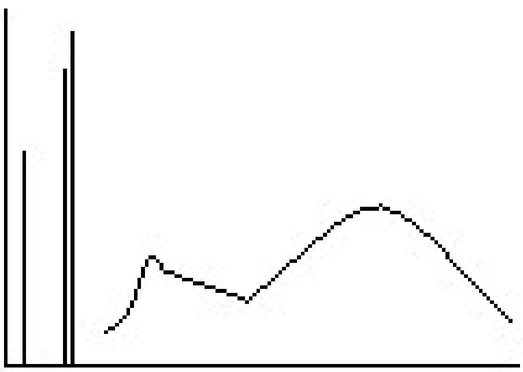


Image Enhancement - Spatial Techniques

- Spectral enhancement relies on changing the gray scale representation of pixels to give an image with more contrast for interpretation

- It applies the same spectral transformation to all pixels with a given gray scale in an image

- However, it does not take full advantage of human recognition capabilities even though it may allow better interpretation of an image by a user

- Several examples will demostrate the value of spatial characteristics in image interpretation

- Spatial enhancement is the mathematical processing of image pixel data to emphasize spatial relationships

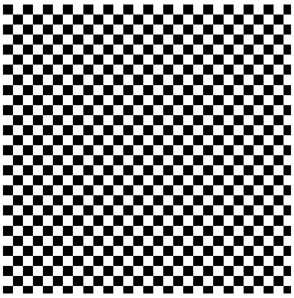
- Spatial enhancement uses the concept of spatial frequency within an image

- Spatial frequency is the manner in which gray-scale values change relative to their neighbors within an image

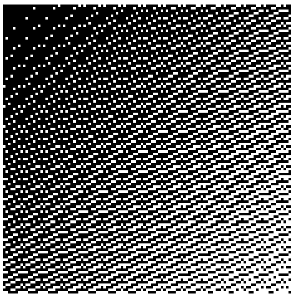
- If there is a slowly varying change in gray scale in an image from one side of the image to the other, the image is said to have a low spatial frequency

- If pixel values vary abruptly for adjacent pixels in an image, the image is said to have a high spatial frequency

- Below Figures show examples of high and low spatial frequencies:



High frequency image



Low frequency image

- Many natural and manmade features in images, such as geologic faults, edges of lakes, roads, airports have high spatial frequency

- Spatial enhancement involves the enhancement of either low or high frequency information within an image

- Algorithms that enhance low frequency image information employ a "blurring" filter (commonly called a low pass filter) that emphasizes low frequency parts of an image while de-emphasizing the high frequency components

- Enhancement of high frequency information within an image is called edge enhancement

- Edge Enhancement emphasizes edges in the image while retaining overall image quality

- There are 3 main purposes that underlie spatial enhancement techniques:

  - To improve interpretability of image data
  - To aid in automated feature extraction
  - To remove and/or reduce sensor degradation

- 2 major methods are commonly used in spatial enhancement:

  1) Convolution
  2) Fourier Transform Theory

<u>Convolution</u>

- Convolution involves the passing of a moving window over an image and creating a new image where each pixel in the new image is a function of the original pixel values within the moving window and the coefficients of the moving window as specified by the user

- The window, a convolution operator, may be considered as a matrix (or mask) of coefficients that are to be multiplied by image pixel values to derive a new pixel value for a resultant enhanced image

- This matrix may be of any size in pixels and does not necessarily have to be square

<u>Example:</u>

- Take a 3 by 3 matrix of coefficients and see the effects on an example image subset

- A set of coefficients that is used for image smoothing and noise removal is given below:

1/9 *	1	1	1
	1	1	1
	1	1	1

- If we have a sample image, given below:

3	3	4	4	5	6
2	3	3	4	4	5
1	2	2	3	3	4
1	1	2	4	4	7
1	2	4	20	20	20
2	3	6	20	20	20
2	3	4	20	20	20

- Above image normally has a low smoothly varying gray scale, except for the bottom right region, which exhibits a sharp brightness change

- We can see the effects of the convolution filter on a pixel-by-pixel basis

- Because we do not wish to consider edge effects, we will start the overlay of the moving window on the x=2, y=2 (x-being the row, y-being the column) pixel of the input image and end at the x=6, y=5 position of the original image

- First pixel of the output image p(x,y) (x=1, y=1), will have brightness value

p(1,1) = 1/9 *	(3*1 +	3*1 +	4*1+	= 23/9 = 2.56
	2*1 +	3*1 +	3*1+	
	1*1 +	2*2 +	2*1)	

- Because the output image, as well as the input image, is normally a whole number (integer) quantity, the values are rounded down to the nearest integer

- Thus p(1,1) = 2

Similarly,

p(1,2) = 1/9 *	(3*1 +	4*1 +	4*1+	= 28/9 = 3.111
	3*1 +	3*1 +	4*1+	
	2*1 +	2*1 +	3*1)	

- Thus p(1,2) = 3 and

p(1,3) = 1/9 *	(4*1 +	4*1 +	5*1 +	= 32/9 = 3.555
	3*1 +	4*1 +	4*1 +	
	2*1 +	3*1 +	3*1)	

- Thus p(1,3) = 3

- Continued application of the same window (or filter kernel) will result in an output image given by:

Convolved image

2	3	3	4
1	2	3	4
1	4	6	9
2	6	11	15
3	9	14	20

- Comparing this convolved image above with the original image below for the same pixel locations to which convolution is applied, it is seen that:

Original image

3	3	4	4
2	2	3	3
1	2	4	4
2	4	20	20
3	6	20	20

- There is sharp discontinuity in the in the original image whereas in the convolved image, sharp discontinuity is smoothed out

- İ.e. the moving window filter (convolution kernel) has a smoothing effect on the original image it is applied to

- A sample edge detection mask can be given as

-1	-1	-1
-1	8	-1
-1	-1	-1

- Then the brightness value of the convolved image p(1,1) will be

p(1,1) =	(-1*3)	+ (-1*3)	+ (-1*4)+	= 4
	(-1*2)	+ (8*3)	+ (-1*3)+	
	(-1*1)	+ (-1*2)	+ (-1*2)	

- Resulting image after application of the mask can be found as

4	-1	4	-2
1	-6	-2	-11
-7	-22	-26	-49
-4	-26	80	45
0	-28	46	0

- Since only positive values are allowed in a image file, all values are offset by the absolute value of the minimum image elements (i.e. add 49 to all the pixels)

- The resultant image is:

53	48	53	47
50	43	47	38
42	27	23	0
45	23	129	98
49	21	95	49

- Values greater than 90 are present in the output image and represent the edge of the bright region in the original image

- Alternatively, negative values can be set to 0 giving an output image of

4	0	4	0
1	0	0	0
0	0	0	0
0	0	80	45
0	0	46	0

- Above output image can be compared with the below original image

3	3	4	4
2	2	3	3
1	2	4	4

2	4	20	20
3	6	20	20

- One of the most used convolution kernels for edge enhancement of images is given by Chavez

- The kernel is specified as:

1/9 *	-1	-1	-1
	-1	17	-1
	-1	-1	-1

- Above kernel is used for enhancement of high frequency information in an image

- For a particular image pixel location and channel number, a low pass filter may be used to evaluate the average value in a 3 by 3 window

- The convolution kernel is then given by:

avg = 1/9 *	1	1	1
	1	1	1
	1	1	1

- High frequency (HF) component in any given pixel wil then be given by:

- HF = pixel - avg

- Represented in terms of a convolution kernel, HF becomes:

HF =	0	0	0	- 1/9 *	1	1	1
	0	1	0		1	1	1
	0	0	0		1	1	1

- İ.e.

HF = 1/9 *	-1	-1	-1
	-1	8	-1
	-1	-1	-1

- By adding the high frequency part, HF, back to the original pixel, a high frequency enhancement will be obtained as:

- New value = pixel value + HF

- This is given by:

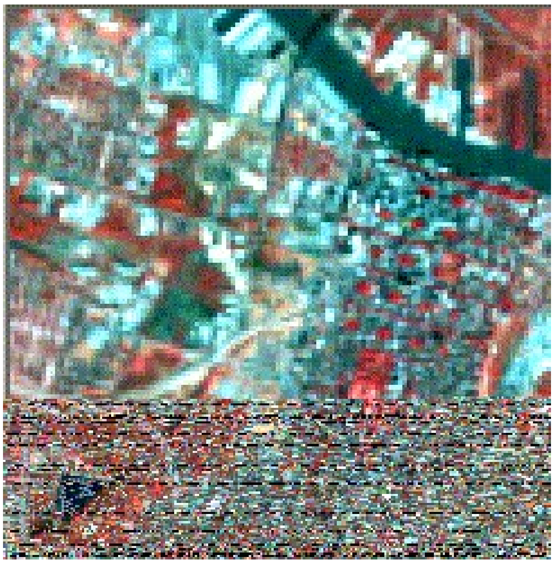
	0	0	0		-1	-1	-1
New value =	0	1	0	+ 1/9 *	-1	8	-1
	0	0	0		-1	-1	-1

or

	-1	-1	-1
New Value = 1/9 *	-1	17	-1
	-1	-1	-1

- Below Figures show Landsat Thematic Mapper (TM) images before enhancement, and after applying the above convolution kernel to the original image

Raw image (Before Enhancement)



After High Frequency Enhancement

Fourier Transform

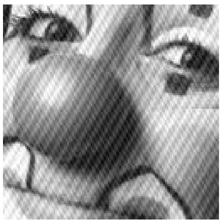
- Fourier Transform as applied to image (2-Dimensional) describes the image in terms of its spatial frequency components

- Fourier Transform is used in a wide range of applications, such as image analysis, image filtering, image reconstruction and image compression.

- Fourier Transform is used to convert images from the spatial domain into the frequency domain and vice-versa.

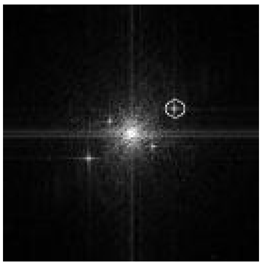
- Fourier Transform helps to visualize and solve certain issues in the spatial frequency domain, which are otherwise very difficult to solve in spatial domain

- For example the below image is covered by noise before Fast Fourier Transform (FFT) is applied

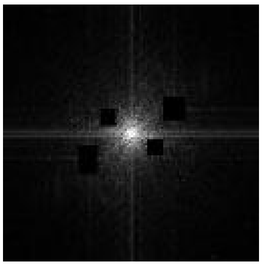


- Below FFT of the above noisy image is shown

- Due to its regularity, the noise pattern stands out as four spikes, one of which is marked



- Below is the picture in which the four noise spikes, which corresponded to the regular noise patterns, have been deleted from the FFT



- Inverse FFT is applied to the above corrected FFT and the below clean image is found

- Fourier Transform is used to decompose an image into its sine and cosine components

- Output of the transformation represents the image in the **Fourier or frequency domain**

- Assume an image **"I"**

- Spatial Frequency Domain **"SFD"** is a space in which each image value at image position F represents the amount that the intensity values in the image **"I"** vary over a specific distance related to F

- In the frequency domain, changes in image position correspond to changes in the spatial frequency (or the rate at which image intensity values are changing in the spatial domain image **"I"**)

- E.g. suppose that there is the value 20 at the point that represents the spatial frequency 0.1 (or 1 period every 10 pixels)

- This means that in the corresponding spatial domain image **"I"**, the intensity values vary from dark to light and back to dark over a distance of 10 pixels

- And also it means that the contrast between the lightest and darkest is 40 gray levels (2 times 20)

- Spatial frequency domain is required because:

  - It makes explicit periodic relationships in the spatial domain and

  - Image processing is more efficient or sometimes it is the only practical procedure when applied in the frequency domain

- Spatial frequency refers to the inverse of the periodicity with which the image intensity values change

- Image features with high spatial frequency (such as edges) are those that change greatly in intensity over short image distances in the spatial domain

- In the Fourier domain image, each point represents a particular frequency contained in the spatial domain image

Discrete Fourier Transform (DFT)

- Only Discrete Fourier Transform (DFT) will be examined since we are interested in the digital images

- DFT is the sampled Fourier Transform and therefore does not contain all frequencies forming an image, but only a set of samples which is large enough to fully describe the spatial domain image

- The number of frequencies corresponds to the number of pixels in the spatial domain image, i.e. the image in the spatial and Fourier domain are of the same size

- For an image of size M×N, the two-dimensional DFT is given by:

$$F(k, l) = (1/MN) \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m,n) \exp\{ - i\, 2\pi[(k\, m / M) + (l\, n / N)] \}$$

where

f(m,n) is the image in the spatial domain, exponential term is the basis function corresponding to each point F(k, l) in the Fourier space

- Above DFT equation can be interpreted as: the value of each point F(k, l) is obtained by multiplying the spatial image with the corresponding base function and summing the result

- The basis functions are sine and cosine waves with increasing frequencies

- F(0,0) represents the DC-component of the image which corresponds to the average brightness

- F(M-1,N-1) represents the highest frequency

- In a similar way, the Fourier image can be re-transformed to the spatial domain

- Inverse Discrete Fourier transform is given by:

$$f(m,n) = (1/MN) \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} F(k, l) \exp\{ i 2\pi[(k m / M) + (l n / N)] \}$$

- To obtain the result for the above equations, a double sum has to be calculated for each image point.

- However, because the Fourier Transform is separable, it can be written as

$$F(k, l) = (1/N) \sum_{n=0}^{N-1} p(k,n) \exp\{ - i 2\pi(l n / N) \}$$

where

$$p(k, n) = (1/M) \sum_{m=0}^{M-1} f(m,n) \exp\{ - i 2\pi(k m / M) \}$$

- Using the above two formulas, the spatial domain image is first transformed into an intermediate image using M one-dimensional Fourier Transforms

- This intermediate image is then transformed into the final image, using *N* one-dimensional Fourier Transforms

- The Fourier Transform produces a complex number valued output image

- Fourier Transformed image can be displayed with two images, either with the **real** and **imaginary** part or with **magnitude** and **phase**

- In image processing, often only the magnitude of the Fourier Transform is displayed, as it contains most of the information of the geometric structure of the spatial domain image

- However, if it is required to re-transform the Fourier image into the correct spatial domain after some processing in the frequency domain, both magnitude and phase of the Fourier image must be preserved

- Fourier transform is used in the calculation of image convolutions

$$g(a,b) = (1/MN) \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m,n)\, h(a - m, b - n)$$

where

f(m,n) is the original image in spatial domain

h (a,b) is the two dimensional impulse response of the filter in the spatial domain (a,b)

g(a,b) is the image in spatial domain (a,b) at the output of the filter

- Convolution theorem is given by

  G(u,v) = F(u,v) H(u,v)

  where G(u,v), F(u,v) and H(u,v) are the Discrete Fourier Transforms of the image at the output of the filter, input image and the Transfer Function of the filter, respectively (All in the spatial frequency domain (u,v))

- Thus g(a,b) can be found by the inverse Discrete Fourier Transform of G(u,v) = F(u,v) H(u,v) as below:

$$g(a,b) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v)\, H(u,v) \exp\{ i\, 2\pi[(a\, u / M) + (b\, v / N)] \}$$

- Computational load of calculating convolutions reduce significantly when the above relationship is used

Use of Fourier Transform

- Fourier Transform is used if it is required to access the geometric characteristics of a spatial domain image

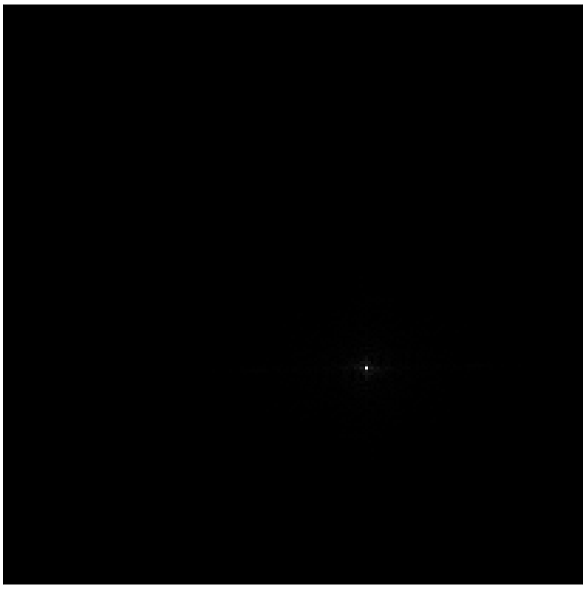
- Because the image in the Fourier domain is decomposed into its sinusoidal components, it is easy to examine or process certain frequencies of the image, thus influencing the geometric structure in the spatial domain

- In most implementations the Fourier image is shifted in such a way that the DC-value (i.e. the image mean) F(0,0) is displayed in the center of the image

- The further away from the center an image point is, the higher is its corresponding frequency

- Consider applying the Fourier Transform to the below image

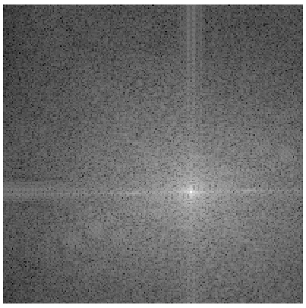
- The magnitude calculated from the complex result is shown below:



- It can be see that the DC-value is the largest component of the image

- The dynamic range of the Fourier coefficients (i.e. the intensity values in the Fourier image) is too large to be displayed on the screen, therefore all other values appear as black

- If a logarithmic transformation is applied to the image the following is obtained

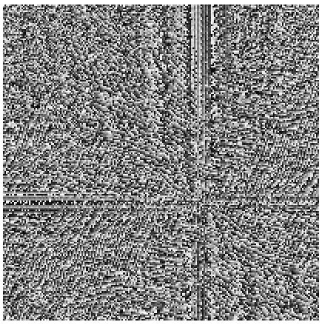


- The result shows that the image contains components of all frequencies, but that their magnitude gets smaller for higher frequencies

- Hence, low frequencies contain more image information than the higher ones

- Transformed image also shows that there are two dominating directions in the Fourier image, one passing vertically and one horizontally through the center. These originate from the regular patterns in the background of the original image

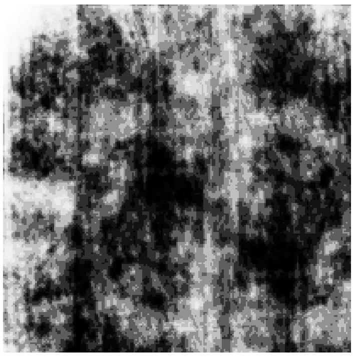
- Phase of the Fourier transform of the same image is shown below



- Value of each point determines the phase of the corresponding frequency

- As in the magnitude image, one can identify the vertical and horizontal lines corresponding to the patterns in the original image

- If inverse Fourier Transform is applied the to the above magnitude image while ignoring the phase (and then histogram equalize the output) below image is obtained



- Although the above image contains the same frequencies (and amount of frequencies) as the original input image, it is so corrupted that it can not be recognized

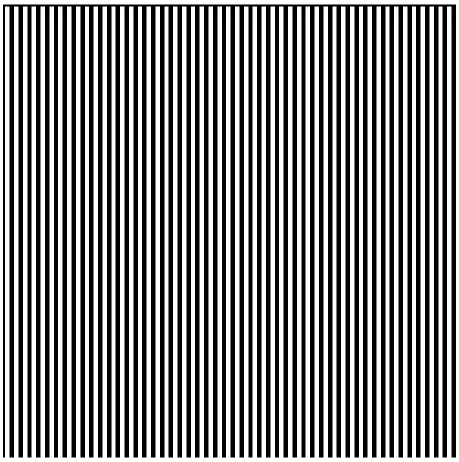
- This shows that the phase information is crucial to reconstruct the correct image in the spatial domain

- The phase image does not yield much new information about the structure of the spatial domain image so in the following examples only the magnitude of the Fourier Transform will be displayed

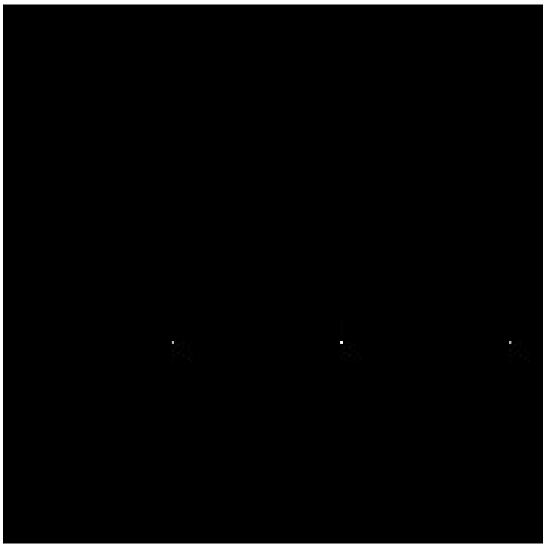
- Below some simple images will be investigated to better understand the nature of the Fourier transform

- Response of the Fourier Transform to periodic patterns in the spatial domain images can be seen in the following artificial images

- The below image shows 2 pixel wide vertical stripes



- Fourier transform of this image is shown below



- Above it can be seen that it contains 3 main values: the DC-value and since the Fourier image is symmetrical to its center, two points corresponding to the frequency of the stripes in the original image

- Note that the two points lie on a horizontal line through the image center, because the image intensity in the spatial domain changes the most if we go along it horizontally

- The distance of the points to the center can be explained as follows: the maximum frequency which can be represented in the spatial domain are one pixel wide stripes

  f_{max}= (1/1 pixel)

- Hence, the two pixel wide stripes in the above image represent

  f = (1/2 pixel) = $f_{max}/2$

- Thus, the points in the Fourier image are halfway between the center and the edge of the image, i.e. the represented frequency is half of the maximum

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