SWAYAM NPTEL COURSE ON

MINE AUTOMATION AND DATA ANALYTICS

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Module 05
Automated Tracking and Communication Technologies

Lecture 13 A
Image Processing and Analysis in Remote Sensing

CONCEPTS COVERED

- Introduction to Remote sensing
- Techniques in remote sensing
- Imaging: Images are captured using optical, infrared, and microwave technologies.
- Processing of Images
- Restoration of Images
- Images Analysis

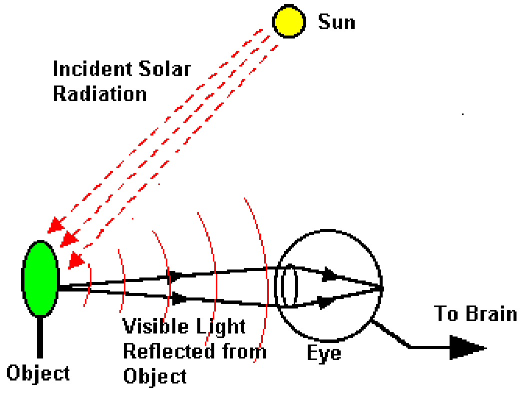
Introduction to Remote sensing

- Generally, Remote sensing refers to the activities of recording/observing/perceiving (sensing) objects or events at far away (remote) places.
- In remote sensing, the sensors are not in direct contact with the objects or events being observed. The information needs a physical carrier to travel from the objects/events to the sensors through an intervening medium.
- The electromagnetic radiation is normally used as an information carrier in remote sensing.

Introduction to Remote sensing

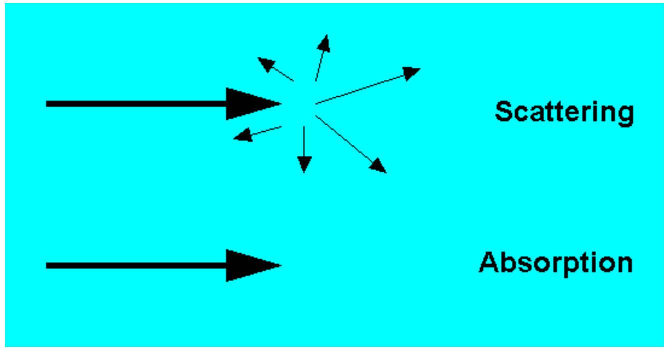
- The output of a remote sensing system is usually an image representing the scene being observed.

- A further step of image analysis and interpretation is required in order to extract useful information from the image. The human visual system is an example of a remote sensing system in this general sense.



Effects of Atmosphere

- Satellite remote sensing involves sensors observing Earth through the atmosphere.
- Understanding atmospheric effects of electromagnetic radiation is crucial.
- Atmospheric constituents cause wavelength-dependent absorption and scattering.
- These effects degrade image quality.
- Some atmospheric effects can be corrected prior to further analysis

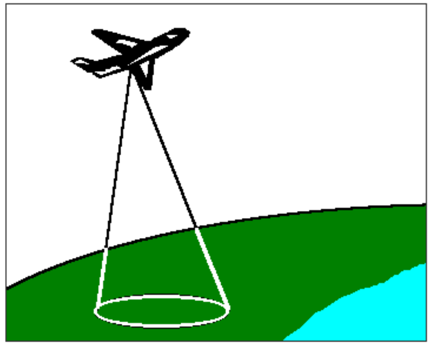


Effects of Atmosphere

- Certain wavelength bands are strongly absorbed by the atmosphere.
- Regions of the electromagnetic spectrum usable for remote sensing are determined by atmospheric transmission windows.
- Remote sensing systems are designed to operate within these windows.
- Transmission windows exist in the microwave, some infrared, visible, and near ultraviolet regions.
- X-rays and gamma rays, although transparent to the atmosphere, are not commonly used in remote sensing of Earth.

Airborne Remote Sensing

- Airborne remote sensing uses sensors mounted on aircraft to capture images of Earth's surface.
- Advantages include very high spatial resolution (20 cm or less).
- Disadvantages include low coverage area and high cost per unit area.
- Airborne remote sensing is not cost-effective for mapping large areas.
- Earth observation satellites allow continuous monitoring.



A high resolution aerial photograph over a forested area. The canopy of each individual tree can be clearly seen. This type of very high resolution imagery is useful in identification of tree types and in assessing the conditions of the trees.

Airborne Remote Sensing

- Common techniques include analog aerial photography, videography, and digital photography.
- Synthetic Aperture Radar imaging is also conducted on airborne platforms.
- Analog photography offers high spatial resolution and visual interpretation by experienced analysts.
- Analog photographs may be digitized for computer-assisted analysis.
- Digital photography enables real-time data transmission for immediate analysis and computer-aided interpretation

Another example of a high resolution aerial photograph over a residential area.

Spaceborne Remote Sensing

In spaceborne remote sensing, sensors are mounted on-board a spacecraft (space shuttle or satellite) orbiting the earth. At present, there are several remote sensing satellites providing imagery for research and operational applications. Spaceborne remote sensing provides the following advantages:

- Large area coverage;
- Frequent and repetitive coverage of an area of interest;
- Quantitative measurement of ground features using radiometrically calibrated sensors;
- Semiautomated computerized processing and analysis;
- Relatively lower cost per unit area of coverage.

Digital Image

- An image is a two-dimensional representation of objects in a real scene.
- Remote sensing images are representations of parts of the earth surface as seen from space.
- The images may be analog or digital. Aerial photographs are examples of analog images while satellite images acquired using electronic sensors are examples of digital images.

Multilayer Image

- Different types of measurements can be made from the ground area covered by a single pixel.
- Each measurement forms an image carrying specific information about the area.
- Stacking these images together forms a multilayer image, with each component image as a layer.
- Multilayer images can also be formed by combining images from different sensors and other data.
- For example, a multilayer image may include layers from SPOT multispectral images, ERS synthetic aperture radar images, and digital elevation maps of the area.

Multispectral Image

Multispectral images consist of multiple layers, each representing a specific wavelength band. Examples include SPOT HRV (3 bands), IKONOS (4 bands), and Landsat TM (7 bands).

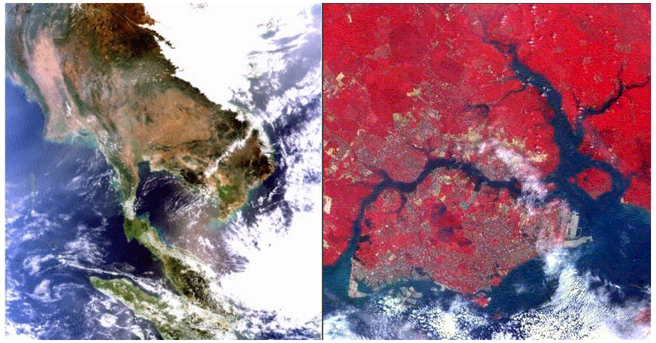
Superspectral Image

- **Modern satellite sensors like MODIS on NASA's TERRA satellite have many more wavelength bands.**
- **MODIS consists of 36 spectral bands covering a wide range from visible to thermal infrared.**
- **These sensors capture finer spectral characteristics with narrower bandwidths.**
- **Such sensors are termed "superspectral."**

Hyperspectral images

- Hyperspectral images consist of over a hundred contiguous spectral bands.
- These images capture the characteristic spectrum of each pixel.
- The precise spectral information enables better target characterization and identification.
- Hyperspectral imagery finds applications in precision agriculture and coastal management.
- Currently, no commercially available hyperspectral imagery from satellites.
- Experimental satellite sensors like NASA's Hyperion and ESA's CHRIS acquire hyperspectral imagery for scientific investigation.

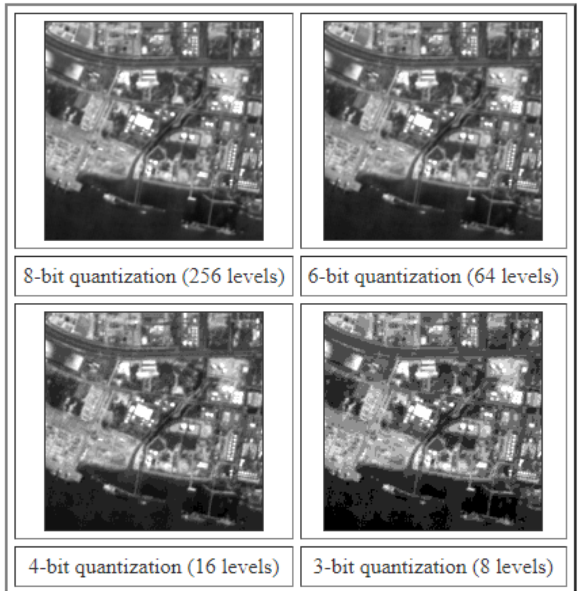
Spatial Resolution



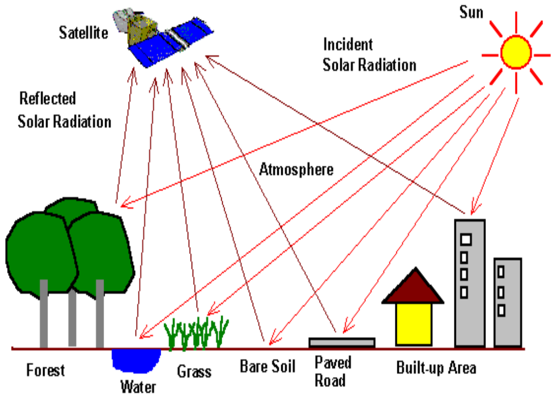
- Spatial resolution is the smallest object size that can be resolved on the ground.
- In digital images, resolution is limited by pixel size.
- Intrinsic resolution is determined by the sensor's instantaneous field of view (IFOV).
- Other factors like improper focusing, atmospheric scattering, and target motion can degrade intrinsic resolution.
- A "High Resolution" image refers to one with a small resolution size. Fine details can be seen in a high-resolution image. On the other hand, a "Low Resolution" image is one with a large resolution size, i.e. only coarse features can be observed in the image.

Radiometric Resolution

Radiometric Resolution refers to the smallest change in intensity level that can be detected by the sensing system. The intrinsic radiometric resolution of a sensing system depends on the signal to noise ratio of the detector. In a digital image, the radiometric resolution is limited by the number of discrete quantization levels used to digitize the continuous intensity value.



Optical and Infrared Remote Sensing

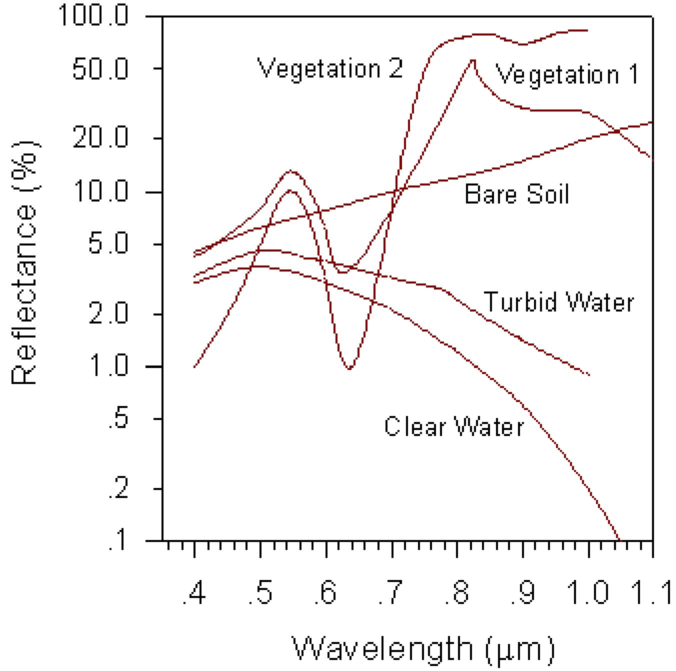


- Optical remote sensing uses sensors to detect solar radiation reflected or scattered from Earth.
- The wavelength region extends from visible and near-infrared (VNIR) to short-wave infrared (SWIR).
- Different materials reflect visible and infrared light differently.
- Interpretation of optical images requires knowledge of spectral reflectance signatures.
- Infrared sensors measure thermal radiation emitted from Earth, enabling temperature derivation of land or sea surfaces.

Spectral Reflectance Signature

When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The reflectance spectrum of a material is a plot of the fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for the material. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials. This premise provides the basis for multispectral remote sensing.

The following graph shows the typical reflectance spectra of five materials: clear water, turbid water, bare soil, and two types of vegetation.



Reflectance Spectrum of Five Types of Landcover

Interpreting Optical Remote Sensing Images

Four main types of information contained in an optical image are often utilized for image interpretation

- Radiometric Information (i.e. brightness, intensity, tone),
- Spectral Information (i.e. color, hue),
- Textural Information,
- Geometric and Contextual Information.

Interpreting Optical Remote Sensing Images

Panchromatic Images

A panchromatic image consists of only one band. It is usually displayed as a grey scale image, i.e. the displayed brightness of a particular pixel is proportional to the pixel digital number which is related to the intensity of solar radiation reflected by the targets in the pixel and detected by the detector. Thus, a panchromatic image may be similarly interpreted as a black-and-white aerial photograph of the area. The Radiometric Information is the main information type utilized in the interpretation.

Interpreting Optical Remote Sensing Images

True Color Composite

If a multispectral image consists of the three visual primary color bands (red, green, blue), the three bands may be combined to produce a "true color" image. For example, the bands 3 (red band), 2 (green band), and 1 (blue band) of a LANDSAT TM image or an IKONOS multispectral image can be assigned respectively to the R, G, and B colors for display. In this way, the colors of the resulting color composite image resemble closely what would be observed by the human eyes.

Interpreting Optical Remote Sensing Images

Vegetation Indices

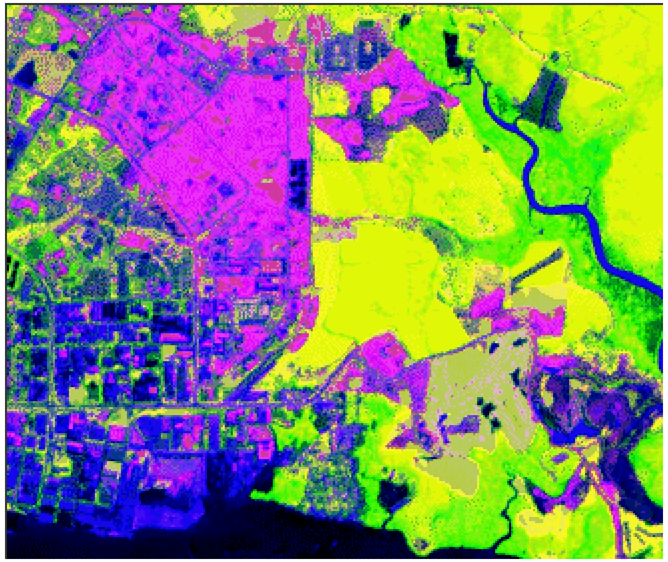
Different bands of a multispectral image may be combined to accentuate the vegetated areas. One such combination is the ratio of the near-infrared band to the red band. This ratio is known as the <u>Ratio Vegetation Index (RVI)</u>

RVI = NIR/Red

Since vegetation has high NIR reflectance but low red reflectance, vegetated areas will have higher RVI values compared to non-vegetated aeras. Another commonly used vegetation index is the Normalized Difference Vegetation Index (NDVI) computed by

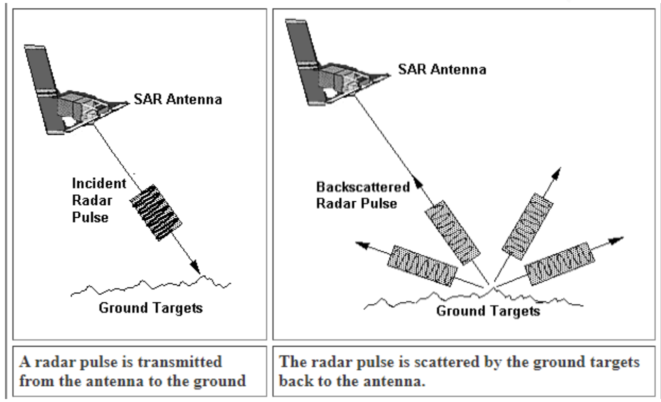
NDVI = (NIR - Red)/(NIR + Red)areas

In the NDVI map shown, the bright areas are vegetated while the non vegetated areas (buildings, clearings, river, sea) are generally dark. Note that the trees lining the roads are clearly visible as grey linear features against the dark background.



The NDVI band may also be combined with other bands of the multispectral image to form a color composite image which helps to discriminate different types of vegetation. One such example is shown.

Microwave Remote Sensing

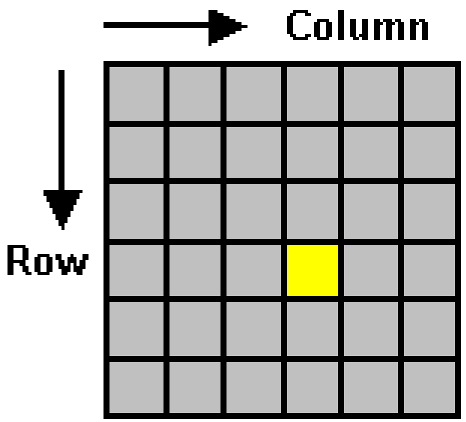


- Some remote sensing satellites carry passive or active microwave sensors.
- Active sensors emit pulses of microwave radiation to illuminate areas for imaging.
- Images are formed by measuring microwave energy scattered back to the sensors.
- These satellites operate like "flashlights," emitting microwaves to illuminate targets.
- Microwave imaging allows acquisition of images day and night, and can penetrate clouds.
- Synthetic Aperture Radar (SAR) is a high-resolution microwave imaging system.
- SAR image intensity depends on microwave backscatter received by the antenna.
- Interpretation of SAR images requires understanding how microwaves interact with targets.

Microwave Remote Sensing

- Electromagnetic radiation in the microwave wavelength region is used in remote sensing to provide useful information about the Earth's atmosphere, land, and ocean.
- A microwave radiometer is a passive device that records the natural microwave emission from the earth. It can be used to measure the total water content of the atmosphere within its field of view.
- A radar altimeter sends out pulses of microwave signals and records the signal scattered back from the earth’s surface. The height of the surface can be measured from the time delay of the return signals.
- A wind scatterometer can be used to measure wind speed and direction over the ocean surface. it sends out pulses of microwaves along several directions and records the magnitude of the signals backscattered from the ocean surface.

Remote Sensing Images

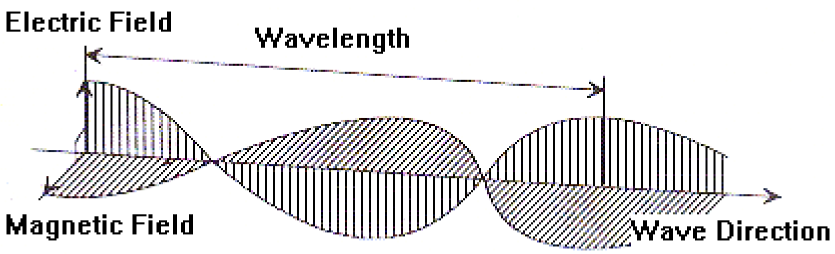


- Remote sensing images are typically in digital form.
- Image processing techniques are used to extract useful information.
- Techniques include enhancement, correction, and restoration of images.
- Methods depend on specific problem requirements.
- Image segmentation and classification algorithms are commonly used.
- These algorithms delineate different areas into thematic classes. Thematic maps are produced as a result. Thematic maps can be combined with other databases for further analysis.

Electromagnetic Radiation

Electromagnetic waves are energy transported through space in the form of periodic disturbances of electric and magnetic fields. All electromagnetic waves travel through space at the same speed, c = 2.99792458 x 10^8 m/s, commonly known as the speed of light. An electromagnetic wave is characterized by a frequency and a wavelength. These two quantities are related to the speed of light by the equation,

speed of light = frequency x wavelength

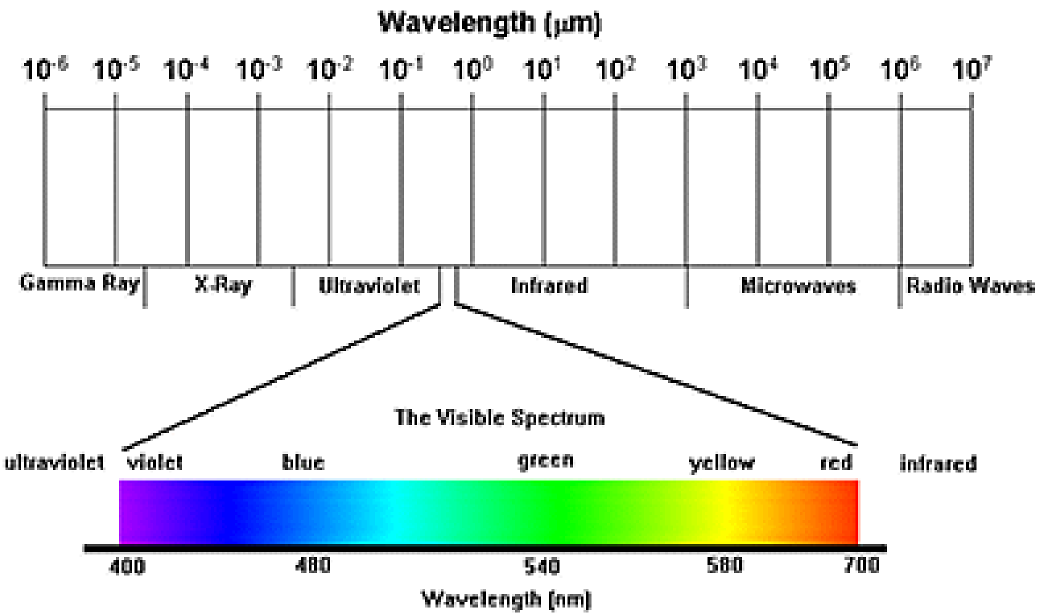


Electromagnetic Radiation

The frequency of an electromagnetic wave depends on its source. There is a wide range of frequency encountered in our physical world, ranging from the low frequency of the electric waves generated by the power transmission lines to the very high frequency of the gamma rays originating from the atomic nuclei. This wide frequency range of electromagnetic waves constitutes the Electromagnetic Spectrum.

Electromagnetic Spectrum

- The electromagnetic spectrum comprises various wavelength (frequency) regions.
- Only a narrow band from about 400 to 700 nm is visible to human eyes.
- Boundaries between these regions are approximate and can overlap.
- There is no sharp boundary between adjacent regions.



Wavelength units: 1 mm = 1000 μm; 1 μm = 1000 nm.

Image Pre-Processing

- Once an image is acquired it is generally processed to eliminate errors

Geometric correction

Radiometric correction

Geometric Correction

Sources of distortion

- Variations in altitude
- Variations in velocity
- Earth curvature
- Relief displacement
- Atmospheric refraction
- Skew distortion from earth's eastward rotation

Geometric Correction

Raw digital images contain two types of geometric distortions are systematic and random

- **Systematic sources are understood and can be corrected by applying formulas.**

- **Random distortions, or ‘residual unknown systematic distortions are corrected using multiple regression of ground control points that are visible from the image.**

Radiometric Correction

Radiance measured at a given point is influenced by

- **Changes in illumination**
- **Atmospheric conditions (haze, clouds)**
- **Angle of view**
- **Instrument response characteristics**
- **Elevation of the sun (seasonal change in sun angle)**
- **Earth-sun distance variation**

Image enhancement

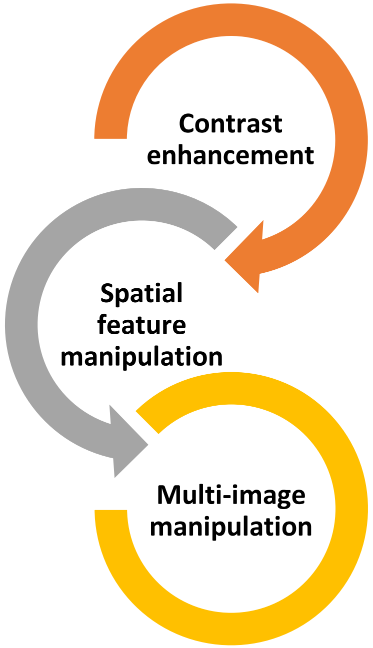
- Improving image quality, particularly contrast It includes a number of methods used for enhancing subtle radiometric differences so that the eye can easily perceive them.

Two types: point and local operations

- Point: modify the brightness value of a given pixel independently
- Local: modify pixel brightness based on neighborhood brightness values

Image enhancement

Three types of manipulation are



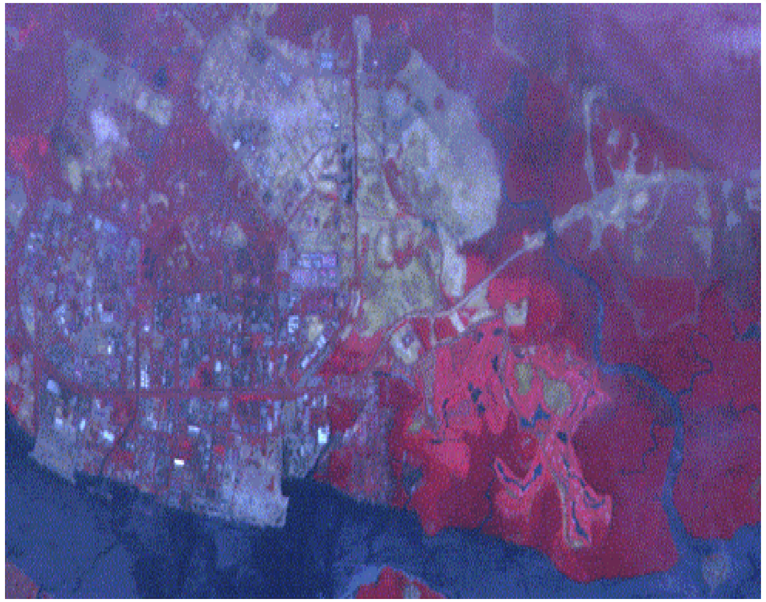
Methods include gray level thresholding, level slicing and contrast stretching.

Methods include spatial filtering, edge enhancement and Fourier analysis.

Methods include multispectral band rationing and differencing, principal components, canonical components, vegetative components, decorrelation stretching, and others.

Contrast enhancement

The image on the left is hazy because of atmospheric scattering; the image is improved (right) through the use of Gray level thresholding. Note that, If there is more contrast and features can be better extracted.



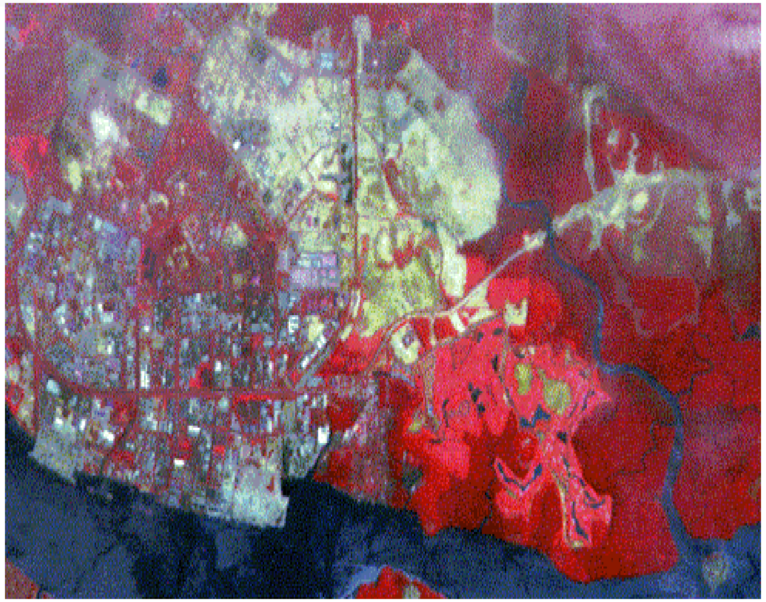
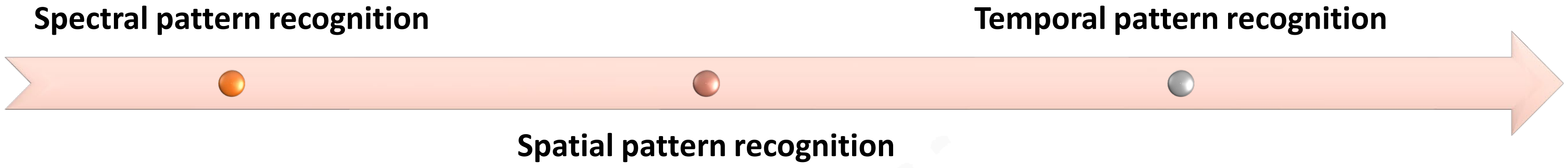


Image classification



- Spectral pattern recognition classifies a pixel based on its pattern of radiance measurements in each band: more common and easy to use
- Spatial pattern recognition classifies a pixel based on its relationship to surrounding pixels: more complex and difficult to implement
- Temporal pattern recognition: looks at changes in pixels over time to assist in feature recognition

Spectral Classification

Two types of classification

- **Supervised:**

The analyst designates on-screen “training areas” known land cover type from which an interpretation key is created, describing the spectral attributes of each cover class. Statistical techniques are then used to assign pixel data to a cover class, based on what class its spectral pattern resembles.

Spectral Classification

- **Unsupervised:**

Automated algorithms produce spectral classes based on natural groupings of multi-band reflectance values (rather than through designation of training areas), and the analyst uses reference data, such as field measurements, DOQs or GIS data layers to assign areas to the given classes.

Spectral Classification

Unsupervised:

- Computer groups all pixels according to their spectral relationships and looks for natural spectral groupings of pixels, called spectral classes
- Assumes that data in different cover classes will not belong to the same grouping
- Once created, the analyst assesses their utility

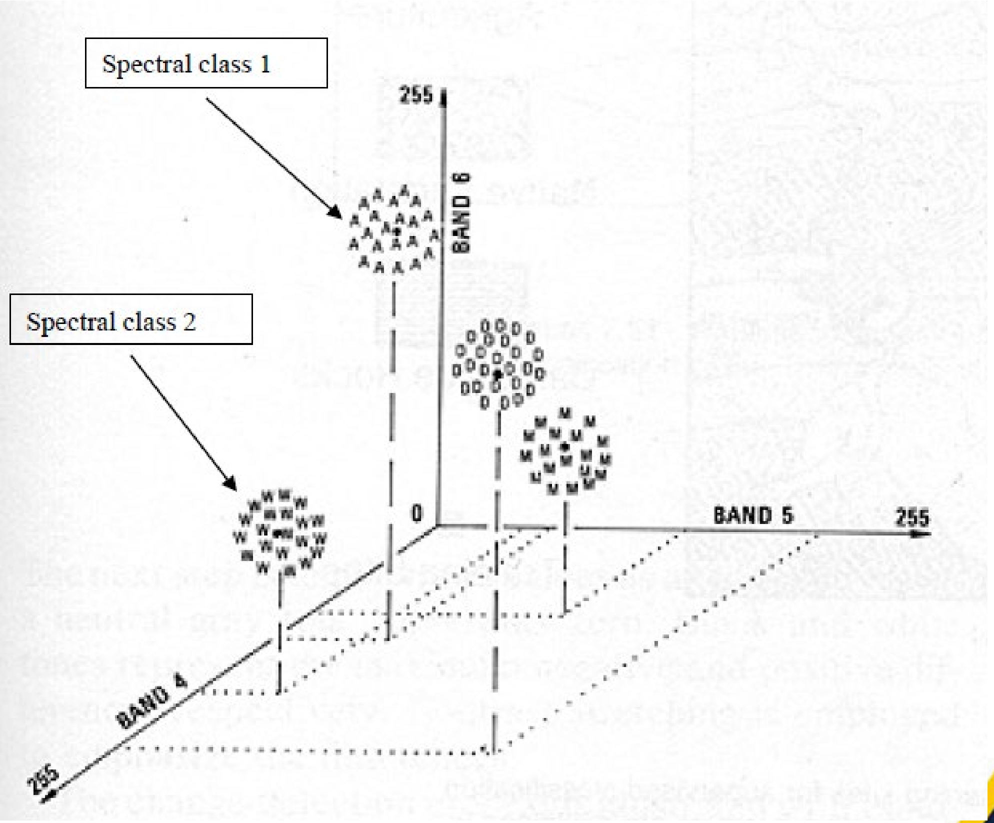


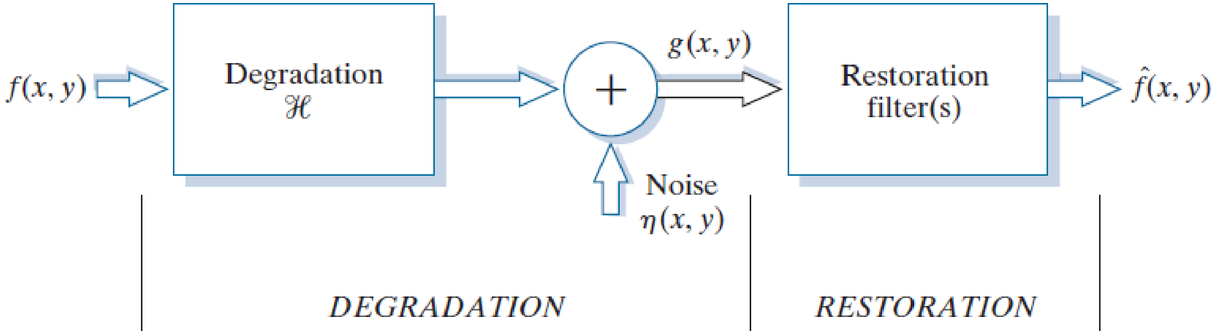
Image Restoration

Restoration techniques are oriented toward modeling the degradation and applying the inverse process in order to recover the original image.

Noise Models

- Digital images can be affected by noise during image acquisition or transmission.
- Imaging sensors' performance is influenced by environmental factors during acquisition and the quality of sensing elements.

- **Factors like light levels and sensor temperature can impact the amount of noise in images captured with a CCD camera.**
- **Transmission channels can introduce interference, corrupting images during transmission.**
- **Examples of interference during transmission include disturbances like lightning or atmospheric conditions in wireless networks.**



Mean Filters

Arithmetic Mean Filter

The arithmetic mean filter computes the average value of the corrupted image, g(x, y), in the area defined by S_{xy}. The value of the restored image fˆ at point (x, y) is the arithmetic mean computed using the pixels in the region defined by S_{xy}.

$$\hat{f}(x,y) = \frac{1}{mn} \sum_{(r,c)\in S_{xy}} g(r,c)$$

Mean Filters

Geometric Mean Filter

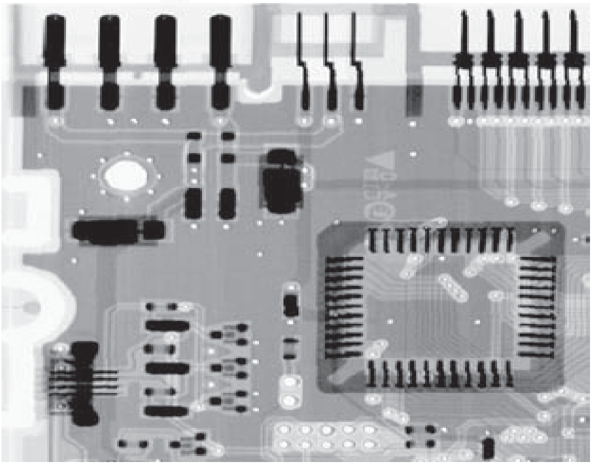
$$\hat{f}(x,y) = \left[\prod_{(r,c)\in S_{xy}} g(r,c) \right]^{\frac{1}{mn}}$$

Harmonic Mean Filter

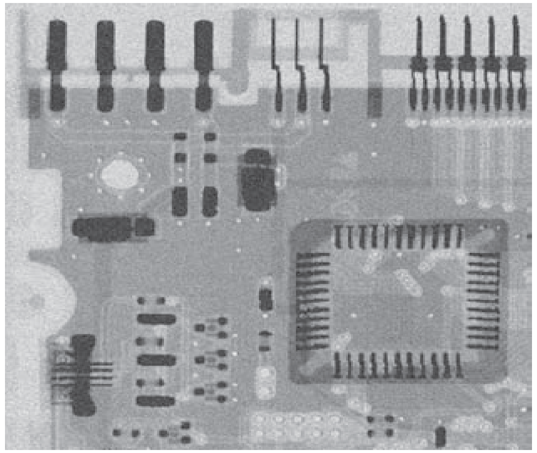
$$\hat{f}(x,y) = \frac{mn}{\displaystyle\sum_{(r,c)\in S_{xy}} \frac{1}{g(r,c)}}$$

Contraharmonic Mean Filter

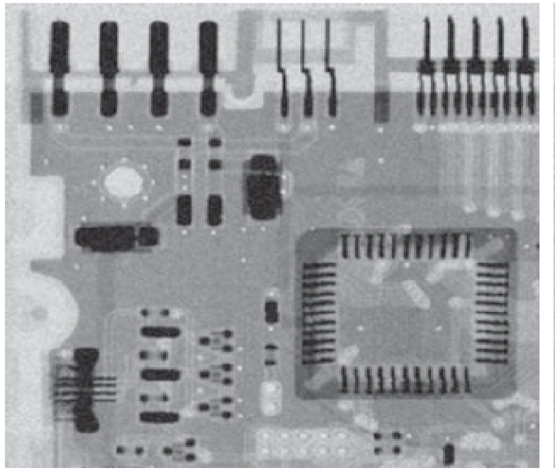
$$\hat{f}(x,y) = \frac{\displaystyle\sum_{(r,c)\in S_{xy}} g(r,c)^{Q+1}}{\displaystyle\sum_{(r,c)\in S_{xy}} g(r,c)^{Q}}$$



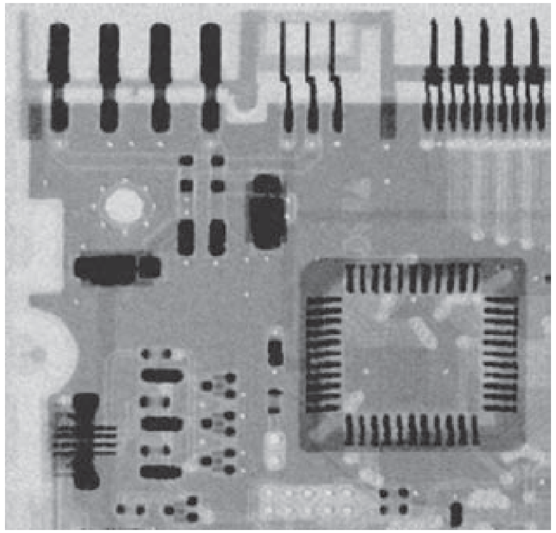
(a) X-ray image of circuit board.



(b) Image corrupted by additive Gaussian noise.



(c) Result of filtering with an arithmetic mean filter of size 3×3.



(d) Result of filtering with a geometric mean filter of the same size.

Image Compression

For transferring images to other devices or due to computational storage constraints, images need to be compressed and cannot be kept at their original size.

Morphological Processing

Image components that are useful in the representation and description of shapes need to be extracted for further processing or downstream tasks. For example, erosion and dilation operations are used to sharpen and blur the edges of objects in an image, respectively.

Image Segmentation

This step involves partitioning an image into different key parts to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze. Image segmentation allows for computers to put attention on the more important parts of the image, discarding the rest, which enables automated systems to have improved performance.

REFERENCES

- https://crisp.nus.edu.sg/~research/tutorial/rsmain.htm
- Gonzalez, R. C., Woods, R. E. (1992). Digital image processing. United Kingdom: Addison-Wesley.,https://www.google.co.in/books/edition/Digital_Image_Processing/C_FRAAAAMAAJ?hl=en&gbpv=0&bsq=Image%20processing

CONCLUSION

- Provided an overview of the remote sensing technology.
- Explored various methods and approaches employed in remote sensing applications.
- Discussed the capture of images using optical, infrared, and microwave technologies in remote sensing.
- Introduced the process of manipulating and enhancing remote sensing images for analysis.
- Explored techniques for improving the quality of degraded or damaged remote sensing images.
- Discussed methodologies for interpreting and extracting meaningful information from remote sensing images.


THANK YOU