Heaven's Light is Our Guide

RAJSHAHI UNIVERSITY OF ENGINEERING & TECHNOLOGY

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Introduction to Remote Sensing :

Remote Sensing is defined as an art or science of observing and gathering information about any object, scene, or phenomenon which exists at a remote location from the point of observation. The word ‘remote’ is used in reference to the existence of something (object of interest) at a distant location or the one which is not present in physical contact.

In the early 1960s, the first time ever, the term remote sensing was coined.

It is an instrument-based technique where the device that performs observation from a distant location is called a remote sensor or simply a sensor which is a satellite or aircraft in space. One of the key elements of this remote sensing technique is electromagnetic radiation.

Following are some scientific definitions of Remote Sensing.

“Remote sensing is the technique of deriving information about objects on the surface of the earth without physically coming into contact with them.”

(Source: India’s National Remote Sensing Agency, June 1995)

“Remote sensing is the non-contact recording of information from the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, sensors, lasers, linear arrays, and/or area arrays located on platforms such as aircraft or spacecraft, and the analysis of acquired information by means of visual and digital image processing”

(Source: John R. Jensen, University of South Carolina)

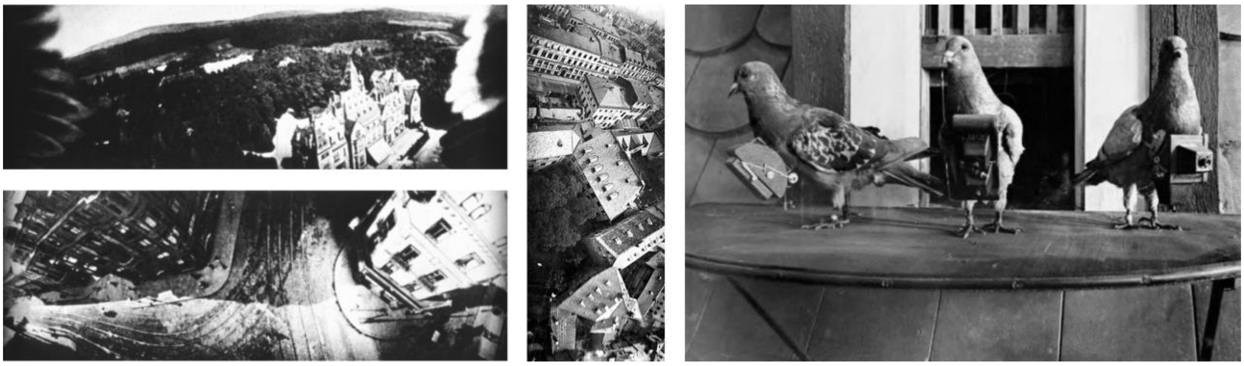
History of Remote Sensing :

The term "remote sensing" is a relatively new term and was first used to describe the field in the 1960s. While the term remote sensing wasn't coined until the mid-twentieth century, remote sensing first began nearly 150 years ago. Aerial photography is the earliest form of remote sensing. This began with the invention of the camera in the 1800s. The first successful photographs were produced in the early 1800s by French inventor Nicéphore Niépce. Soon after the development of photography, people became interested in taking aerial photographs. The earliest aerial photographs were taken from balloons.

In 1850 Gaspard-Félix Tournachon, more commonly known by his pseudonym Nadar, captured the first aerial photograph. Using a hot air balloon, Nadar produced the first successful aerial photograph of a French village in 1858. Unfortunately none of these early aerial photographs exist today. The oldest aerial photograph that has survived was taken in Boston in 1860 by James Wallace Black. Nadar's earliest surviving aerial image was taken from a balloon above Paris in 1866.

1858 - First Aerial Photographer

In the early 20th century remote sensing images were captured using kites and even with cameras mounted on pigeons. In Europe carrier pigeons were already being used in military communication and aerial reconnaissance was an appealing application. Small light weight cameras were attached to the birds and photos were automatically taken using a timing mechanism. The pigeon photography was successful but didn't become widely used due to the rapid development of aviation technology.

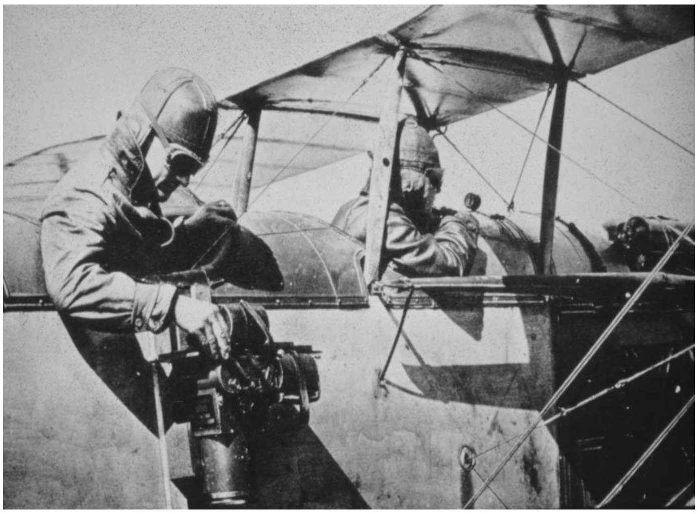


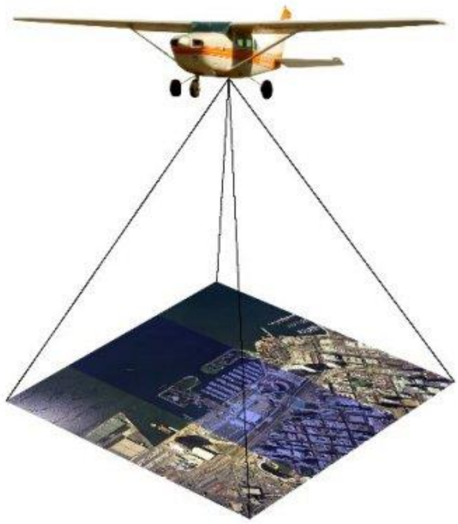
Collage of pigeons with Julius Neubronner's cameras and three aerial photos taken by the method. The photos were taken in the early 1900s in Germany.

In 1906 professional photographer George Lawrence used a string of kites to raise a 49 pound camera 1000 feet in the air to capture the devastation of the earthquake in San Francisco. The famous photograph "San Francisco in Ruins" was taken 6 weeks after the earthquake and subsequent fires in San Francisco.

"*San Francisco in Ruins,*" *by George Lawrence 1906*

The first government-organized air photography missions were developed for military surveillance during World Wars I and II by Europe. they found that Aircraft are more reliable and more stable platforms for earth observation than balloons. The use of aerial photographs for civilian purposes began in the years between World Wars I and II. At the time, geology, forestry, agriculture, and cartography were among the application fields for aerial photographs. These advancements result in better cameras, films, and interpreting technology.



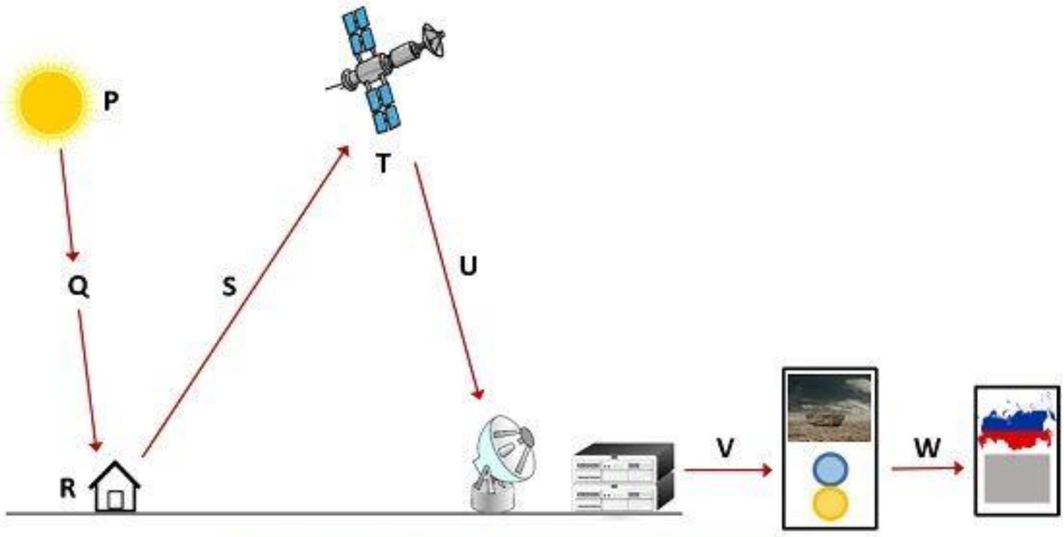


Aerial Photography

In recent years, advances in sensor technology and the increased availability of satellite data have led to a significant expansion of the field of remote sensing. New sensors, such as radar and lidar, have been developed to provide new types of information, and the development of machine learning and other data analysis techniques has made it possible to extract more information from satellite data than ever before. Remote sensing technology is becoming an important tool for monitoring the earth and its resources and will be increasingly used in the future.

Working Principle of Remote Sensing :

Consider the figure shown below in order to understand the various stages involved in remote sensing data acquisition:



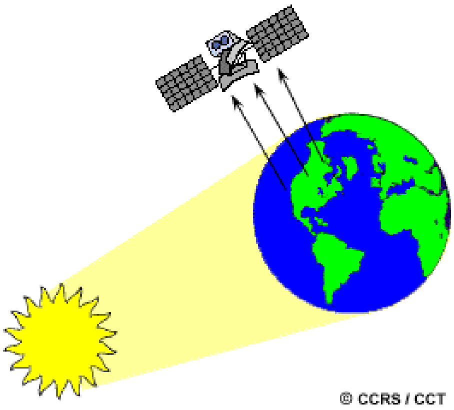
Stages in Remote Sensing

i) Energy Source (P) : The first and foremost requirement for remote sensing is to have an energy source that would illuminate the target object so that the object can reflect some portion of the energy it receives from the source and we can analyze the reflected energy for better understanding of the object.

Now , this source can be the sun or the sensor itself. Depending on it the sensor is two types : passive sensor and active sensor.

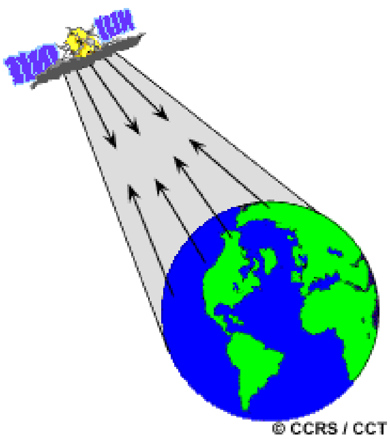
Passive Sensor : The type of remote sensing that makes use of a natural source of energy i.e., the sun in order to produce electromagnetic radiation and perform remote sensing is called passive sensor.

Passive sensors can only be used to detect energy when the naturally occurring energy is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth. There is no reflected energy available from the sun at night.



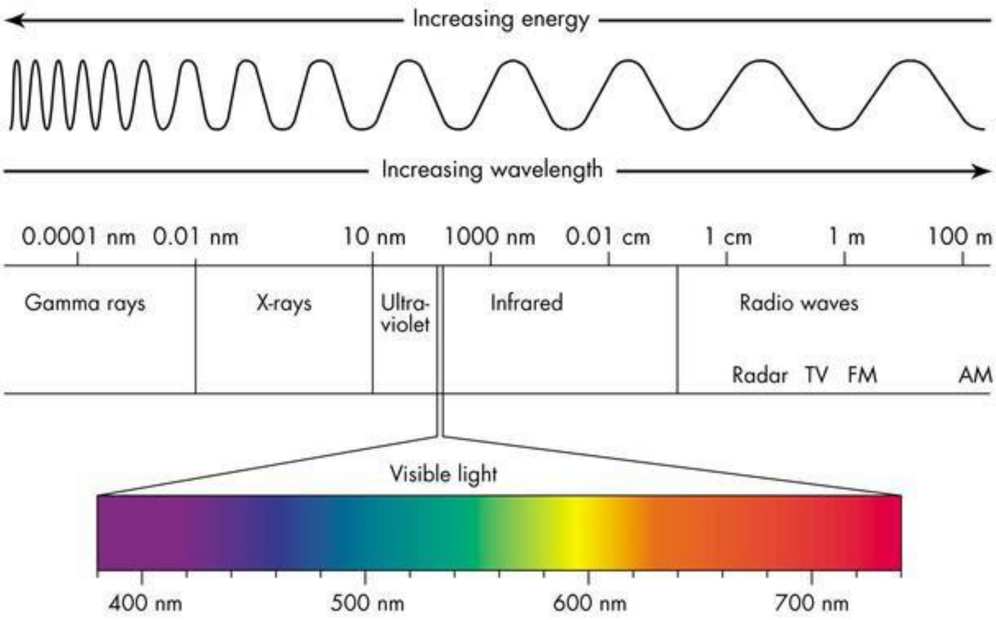
Passive Sensor

Active Sensor : Active sensors, on the other hand, provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets. Some examples of active sensors are a laser fluorosensor and a synthetic aperture radar (SAR).



Active Sensor

The energy coming from source is actually transmitted as an electromagnetic spectrum which is basically nothing but a collection of numerous bands or channels or wavelength ranges. The entire electromagnetic spectrum, from the lowest to the highest frequency (longest to shortest wavelength), includes all radio waves (e.g., commercial radio and television, microwaves, radar), infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Only the visible light which ranges from 400 nm to 700 nm can be seen by human eye.

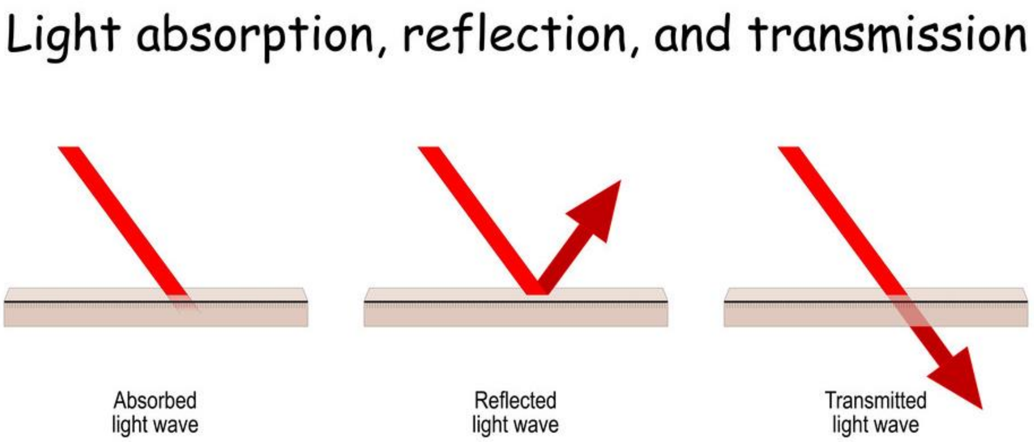


Electromagnetic Spectrum

ii) Energy transmission from source to the earth surface (Q): When the energy is emitted by the source then during transmission, absorption, and scattering of the electromagnetic radiation take place. Basically, the energy from the source propagates with the speed of light.

iii) Target Object (R) : When the object or the specific area, we are interested in, receives the energy transmitted from the source , three possible things can happen :

- Reflection : Reflection is the process by which electromagnetic radiation is returned either at the boundary between two media (surface reflection) or at the interior of a medium (volume reflection)
- Transmission : Transmission is the passage of electromagnetic radiation through a medium.
- Absorption : Absorption is the transformation of radiant power to another type of energy, usually heat, by interaction with matter.



Absorption , Reflection and Transmission

But when it comes to remote sensing , what we all care about is the portion of the energy that is reflected from the object or the area.

iv) Energy transmission from object to sensor (S): The energy from the source after getting reflected from the object re-enters into the atmospheric region. The constituents of the atmosphere such as water molecules, various gases modify the original energy.

v) Energy recording by the sensor (T): The most crucial stage in remote sensing technology is receiving the reflected energy from our target object. The reason is all the fundamental works are done in this step. But before diving deep into this topic let's understand what is sensor and what is platform.

- Sensor : Any device that captures reflected electromagnetic radiation coming from an object or surface is called a sensor. For example – cameras or scanners.
- Platform : The vehicle on which the sensor is carried is known as a platform. For example - satellites or aircraft.

Now, here comes two terminologies that we need to know to measure how good a sensor can take photo of our interest and extract information from it. These two terminologies are spatial resolution and spectral resolution

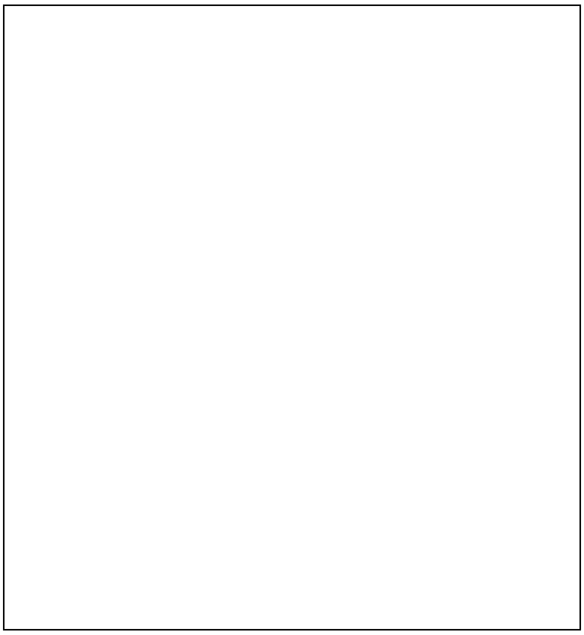
Spatial Resolution : In simple words , spatial resolution refers to the total number of pixel in an image. A pixel is the smallest unit of a digital image.The image quality mostly depends on how much pixels it contains. The higher resolution means the higher number of pixel and the higher number of pixel provides the more detailing of an image. That's why more information can be observed from an image with higher spatial resolution.

Similarly in remote sensing , our goal is to minimize the size of a single pixel as much as we can so that the target area can have maximum number of pixel to gain more information from it.

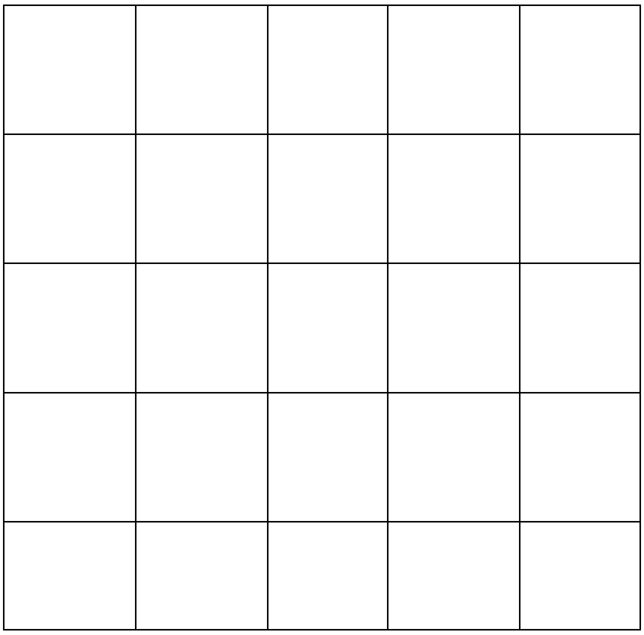
But , how much smallest portion from the target area will be counted as a single pixel , depends on the spatial resolution power of a sensor. To understand how the number of pixel impacts heavily in getting information , let's take two cases as examples.

First Case : if the size of the target area is 100m × 100m and the spatial resolution of a sensor is 20m , then the smallest area that , the sensor is able to detect from the whole target area is , 20m × 20m.

Thus, the total number of pixel in that target area is = $\frac{Total\ Area}{Pixel\ Size} = \frac{100 \times 100}{20 \times 20}$ = 25



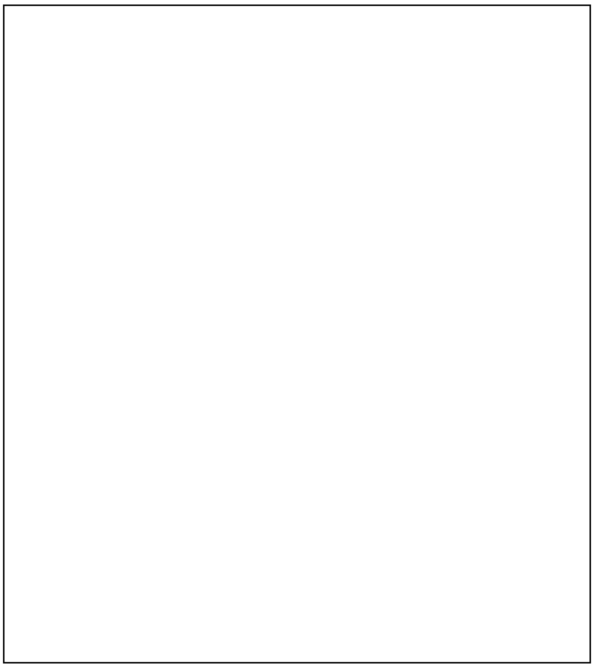
Target Area of 100m × 100m



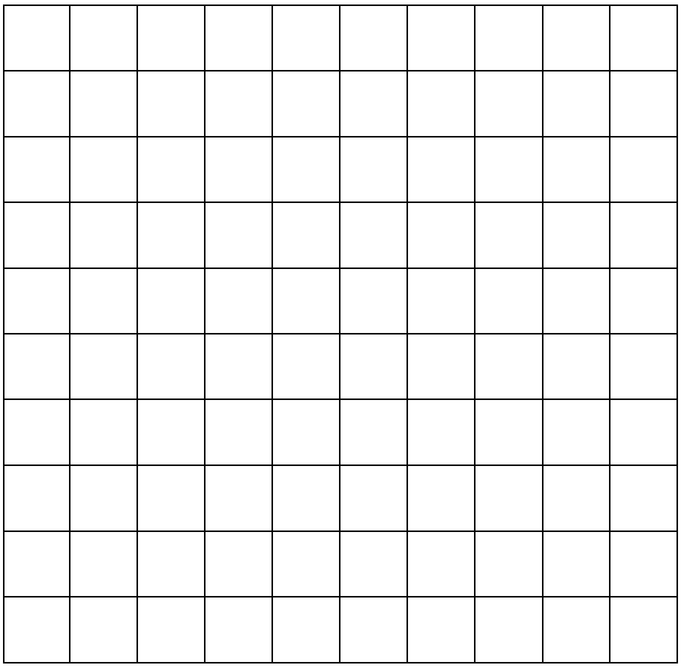
Diving target area with 25 pixels

Second Case : if the size of the target area is 100m × 100m and the spatial resolution of a sensor is 10m , then the smallest area that , the sensor is able to detect from the whole target area is , 10m × 10m.

Thus,the total number of pixel in that target area is = $\frac{Total\ Area}{Pixel\ Size} = \frac{100 \times 100}{10 \times 10}$ = 100



Target Area of 100m ×100m



Diving target area with 100 pixels

So from the two cases explained above , it is vivid that , we can more clearly and precisely observe the target area in second case than in first case. Since , the pixel size is much smaller in second case , the number of pixels contained in the target area in second case is four times higher than in first case.

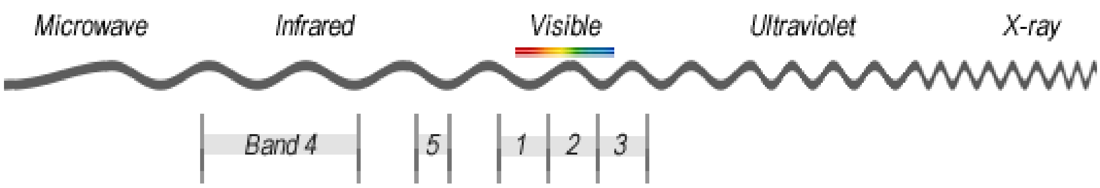
Overall, spatial resolution describes the quality of an image and how detailed objects are in an image. If the grid cells are smaller, this means the spatial resolution has more detail with more pixels.

Spectral Resolution : Spectral resolution is the number of bands or channels or different wavelength ranges that a sensor can detect and collect from the electromagnetic spectrum which is reflected from the target object located in earth surface. The electromagnetic spectrum has several bands and very few of them are actually visible to our human eye. But most of the bands in EMS are out of human visible range and thus , we can't see in our naked eye. So with the tiny visible range ,we are missing lots of information lying in other bands.

So the higher spectral resolution of a sensor indicates that the sensor is able to detect and collect large amount of bands from the reflected electromagnetic spectrum. Thus , the huge amount of data and information that have been hidden in those bands or channel can be gained with that sensor.

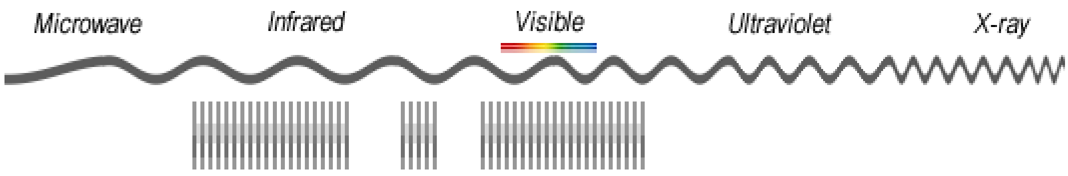
So one of the most important properties of a sensor is it's spectral resolution. Mostly talked sensors in today's world are basically Multispectral Sensor and Hyperspectral Sensor.

Multispectral Sensor : Multispectral sensor can only detect about 3 to 15 bands from electromagnetic spectrum. That's why not much information about the object can be gained using multispectral sensor



For example , from the above EMS , the sensor is only detecting 5 bands which is very few. Thus , Very few data can be received and a large amount of information remain hidden in other bands since multispectral sensor can't capture other bands.

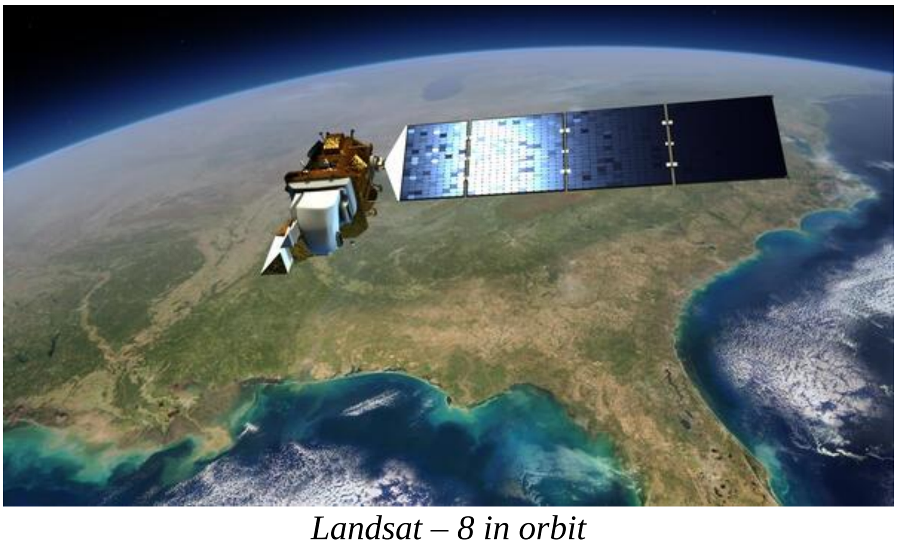
Hyperspectral Sensor : Hyperspectral sensor can detect about hundreds or thousands of bands from electromagnetic spectrum which is a very much great amount compared to multispectral sensor. That’s why huge much information about the object can be gained using hyperspectral sensor.



For example , from the above EMS , the sensor is only detecting more than 50 bands which is massive. Thus , very enormous amount of data can be received.

Spacial and Spectral Resolution Example : Now let’s try to understand how multispectral or hyperspectral image of the target area is produced in the sensor using spatial and spectral resolution.

Landsat – 8 can be takes as example. Landsat 8 (formerly the Landsat Data Continuity Mission, or LDCM) was launched on an Atlas-V rocket from Vandenberg Air Force Base, California on February 11, 2013.



Landsat – 8 in orbit

The satellite carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments.The OLI measures in the visible, near infrared, and shortwave infrared portions (VNIR, NIR, and SWIR) of the spectrum. The TIRS measures land surface temperature in two thermal bands with a new technology that applies quantum physics to detect heat.

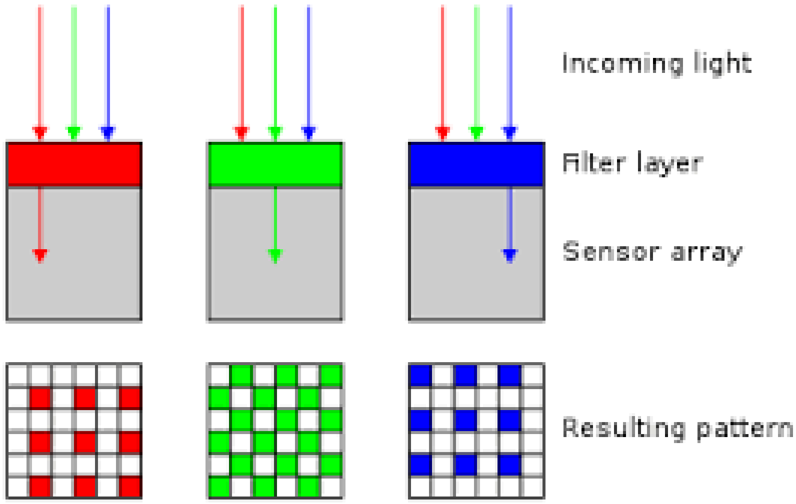
Landsat – 8 has the spectral resolution of 11. That means that Landsat – 8 has the ability to detect and collect 11 different bands from the electromagnetic spectrum that is reflected from the target object located in earth surface.

But for the sake of simplicity , let’s discuss about first 7 bands.

Band Number	Band Name	Wavelength (nanometers)	Spatial Resolution
Band 1	Coastal Aerosol	430 – 450	30m
Band 2	Blue	450 – 510	30m
Band 3	Green	530 – 590	30m
Band 4	Red	640 – 670	30m
Band 5	Near Infrared (NIR)	850 – 880	30m
Band 6	Shortwave infrared (SWIR 1)	1570 – 1650	30m
Band 7	Shortwave infrared (SWIR 2)	2110 – 2290	30m

Table 1 : 7 bands of Landsat - 8

Now here comes the concept that we need to have a clear idea on. When we say that, the spectral resolution of a sensor is ‘n’ , then it means that the sensor is able to detect and collect ‘n’ number of bands or channels from the electromagnetic spectrum reflected from the target area. The thing is, to detect ‘n’ number of different bands from EMS, the sensor must have equal number of filters for each bands. That means that the sensor must have ‘n’ number of filters to capture each different bands. Every filter is only sensitive to one band and it only captures that band and filters out other bands.



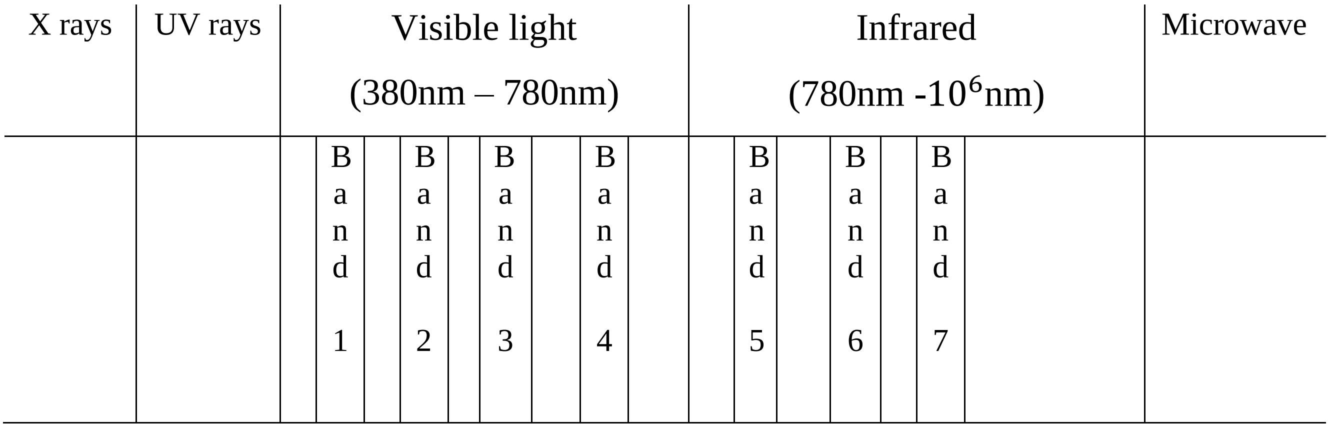
For example in digital camera, the spectral resolution is 3 and it means that it can detect 3 bands : Red , Green and Blue from the EMS. So for all 3 bands , there are 3 filters , one for red , one for blue and another one for green.

From the picture it is seen that the filter for red band only captures red band and filters out green bands and blue bands.

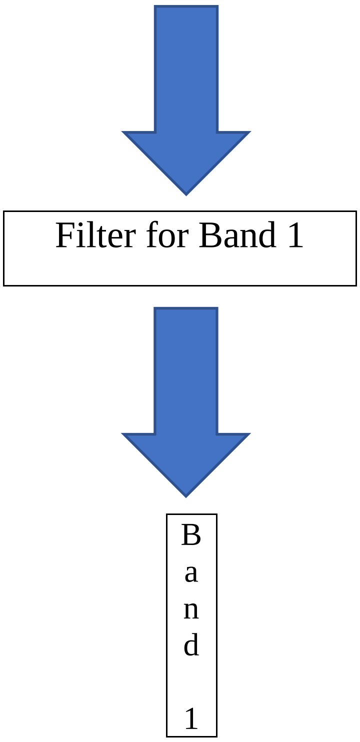
Similarly , The filter for green band only captures green band and filters out red bands and blue bands. The filter for blue band only captures blue band and filter out other bands.

Now let’s go back to our Landsat – 8 in which we have assumed that there are 7 bands. So there must be 7 filters for each band.

Like in digital camera , each filter receives corresponding band or channel and filters out other bands. Let’s visualize how all these things work.



Electromagnetic Spectrum



Here , Filter for band 1 or Coastal Aerosol only receives the wavelength range from 430 to 450 from EMS and filters out other bands. This is how filter for other bands also work.

Formation of Grayscale Image : Now that we have understood the concept of spatial resolution and spectral resolution , it's time to know how grayscale image is formed.

We have come to know that the number of filters required for sensor is as same as the number of bands it can detect. Each filter captures it's corresponding band from the electromagnetic spectrum and a grayscale image is formed behind the scene.

Now let's understand the formation of grayscale image with the help of Landsat-8 that has spectral resolution of 7 (Actually 11, but for the sake of avoiding complexity , we have assumed it to be 7). The name , wavelength and spatial resolution of each band has been described at table 1.

From table 1 , it is seen that spatial resolution of each band is 30m. That means that the smallest unit or the smallest area that the Landsat – 8 can cover or measure from the target are is 30m × 30m.

Let's assume , the total area of that target area is 60m × 60m.

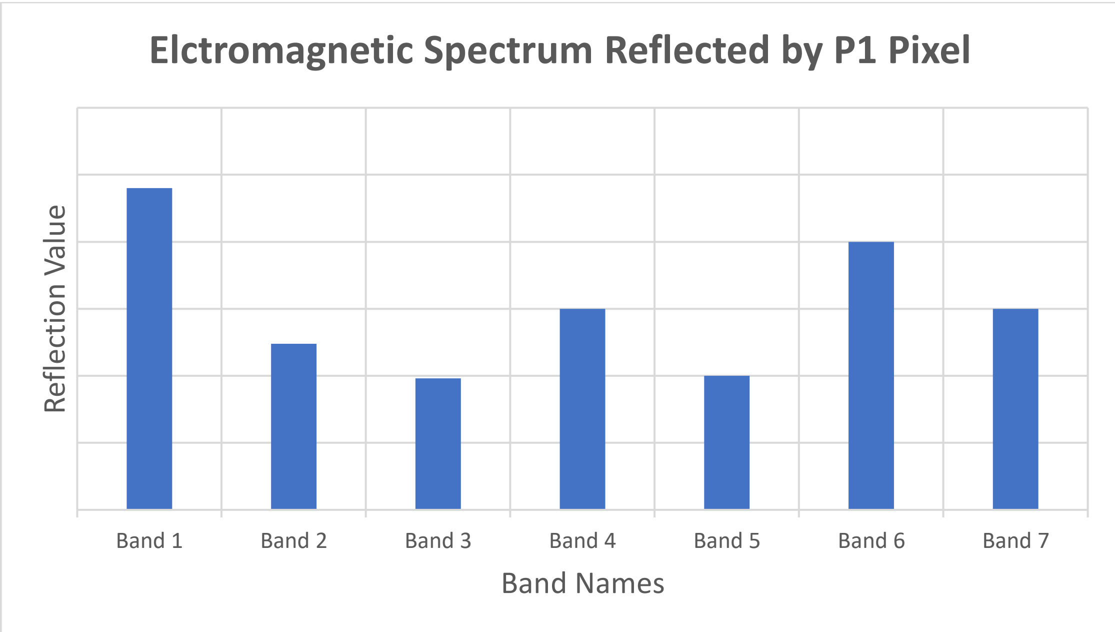
So, the total number of pixel in that target area is = $\frac{Total\ Area}{Pixel\ Size} = \frac{60\times60}{30\times30} = 4$

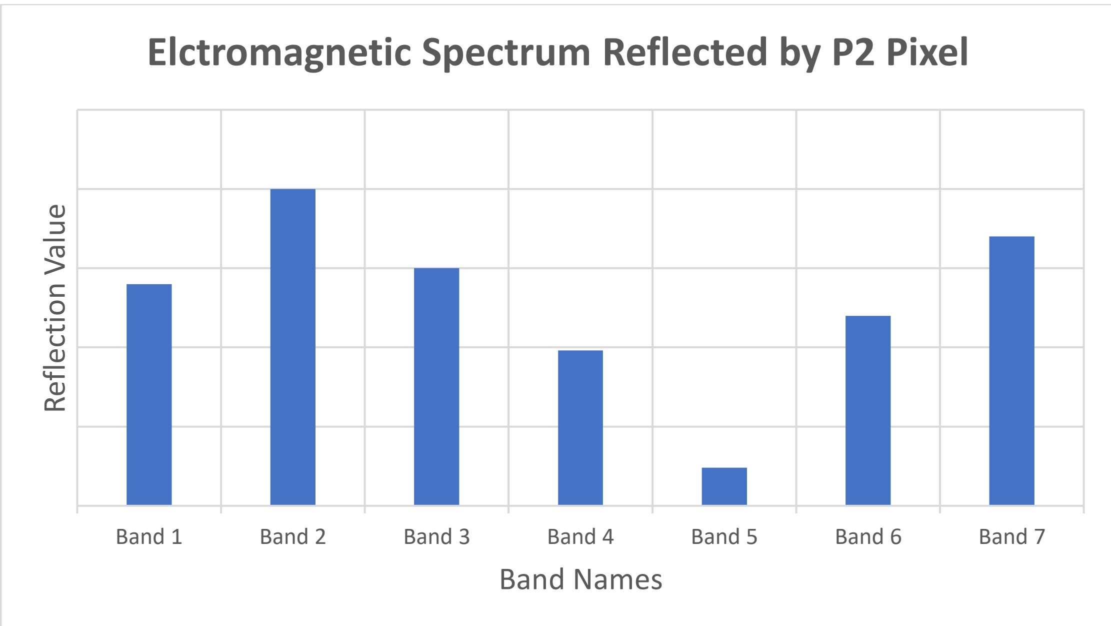
P1	P2
P3	P4

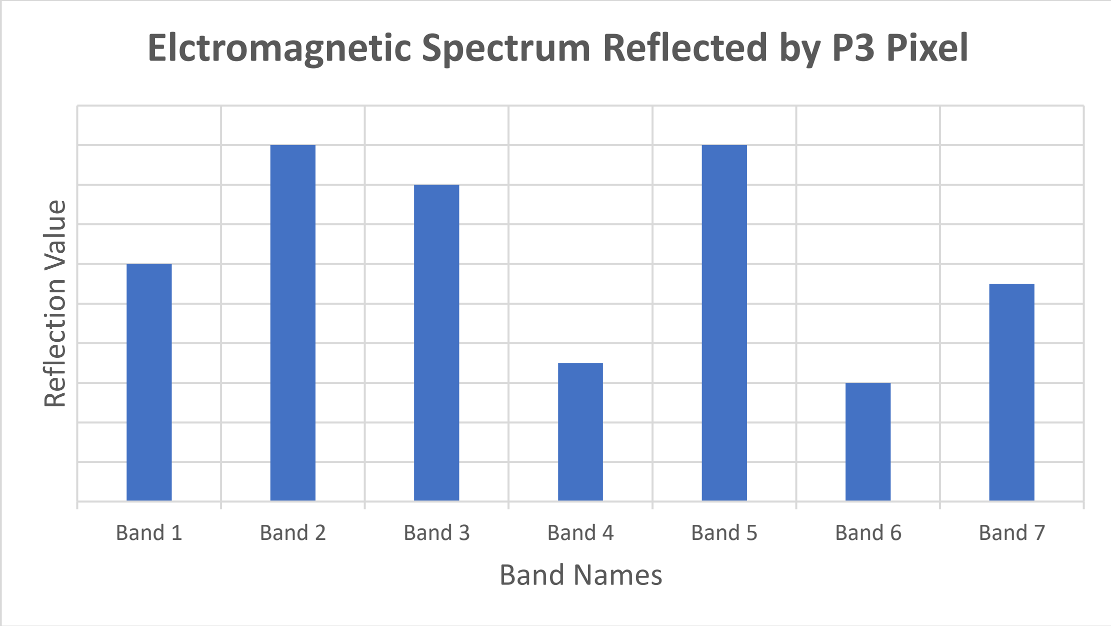
Target area being divided by 4 pixels

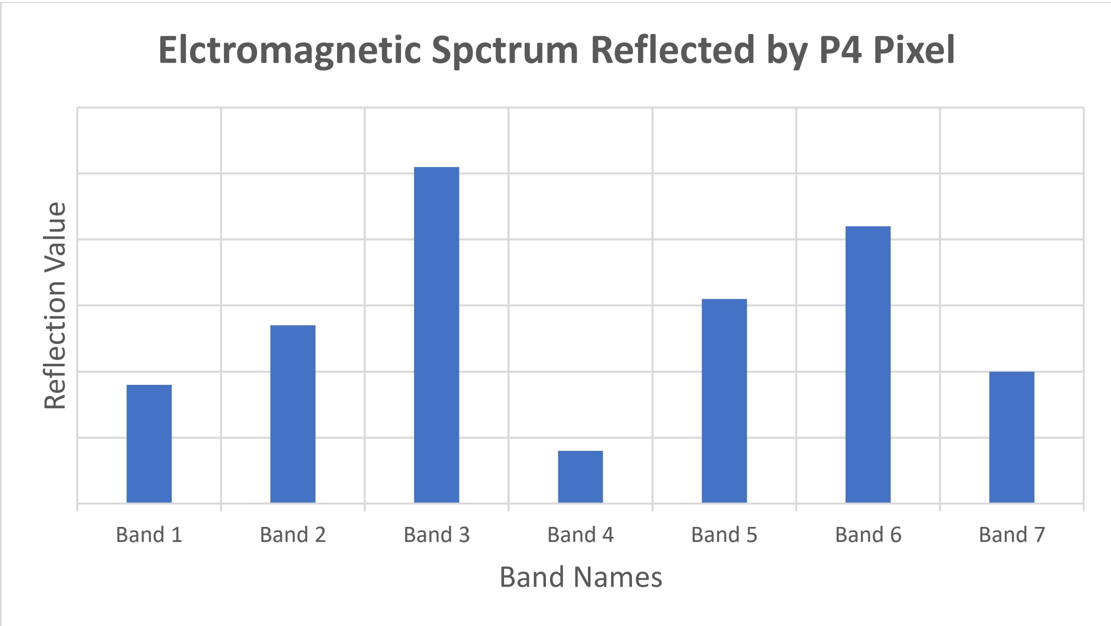
So , when the target area is illuminated with the source energy , the target area will reflect some portion of the energy it receives. Since the target area is now divided with 4 pixels , we can say that these 4 pixels P1 , P2 , P3 and P4 will individually reflect the energy which is in electromagnetic spectrum form.

Let’s consider these following 4 graphs that represent the electromagnetic spectrum reflected by P1,P2,P3 and P4 pixels respectively.









If filter for band 1 is used in the sensor , then only the portion of band 1 from all these 4 electromagnetic spectrum reflected by P1,P2,P3 and P4 pixel will be caught by that filter and a corresponding grayscale image for band 1 will be formed behind the filter. This grayscale image will have as same number of pixel as the target area. Now the intensity level of these 4 pixels in grayscale image formed by band 1 filter, depends on , how much these 4 pixels in target area are reflecting band 1 portion of the electromagnetic spectrum.

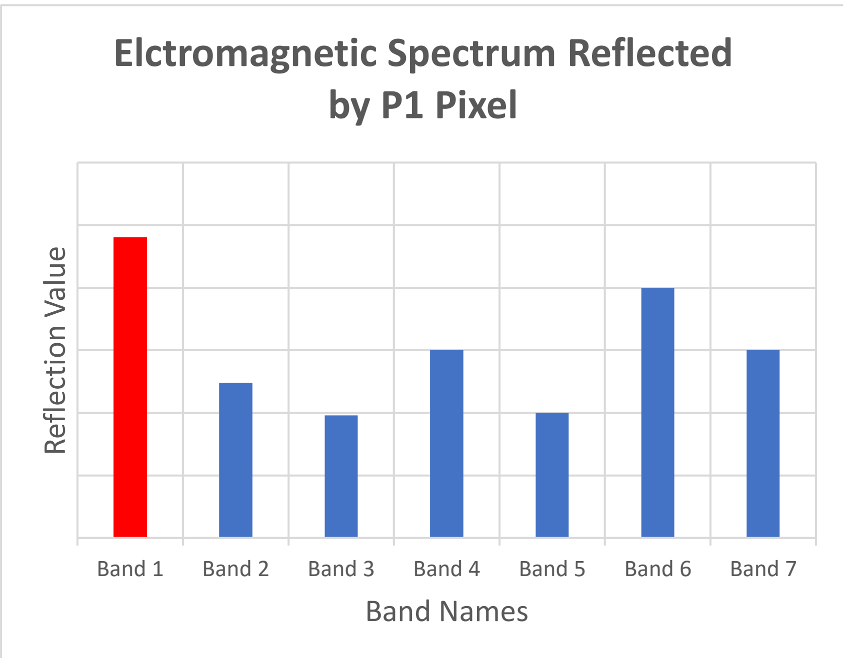
For example , if P1 pixel has a great reflection value of band 1 , then the intensity value of P1 pixel in grayscale image would be very high.

If each pixel in grayscale image is represented by 8 bits , then each pixel can have 2^8 = 256 intensity levels ranging from 0 to 255.

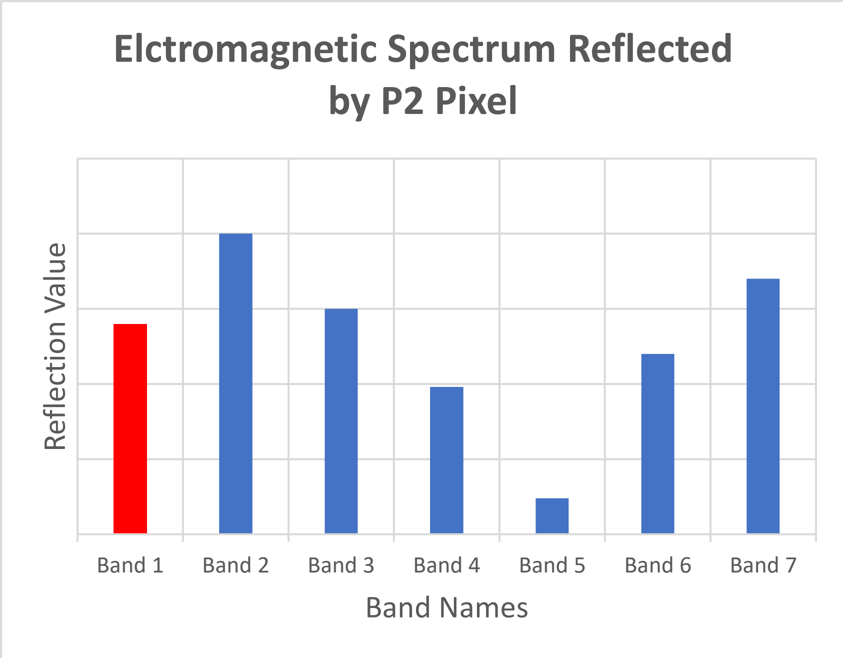
So , for a great reflection value of band 1 from P1 pixel in target area , corresponding P1 pixel in grayscale image formed by band 1 filter can have intensity value close to 255.

But for a less reflection value of band 1 from P1 pixel in target area , corresponding P1 pixel in grayscale image formed by band 1 filter will have intensity value close to 0.

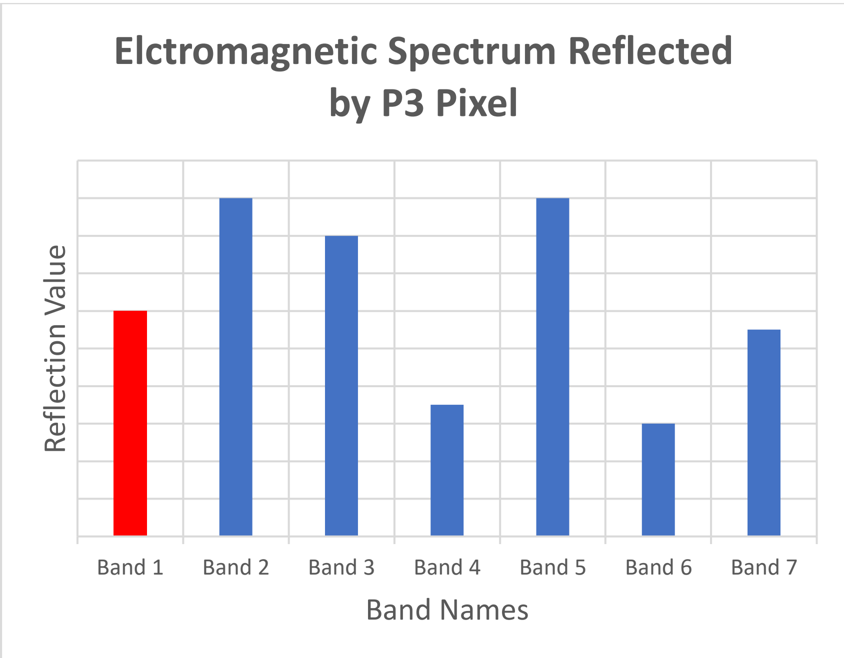
Now , Let's analyze the 4 graphs representing electromagnetic spectrum reflected by P1,P2,P3 and P4 pixels and guess the intensity value of corresponding P1,P2,P3 and P4 pixels in grayscale image formed by band 1 filter.



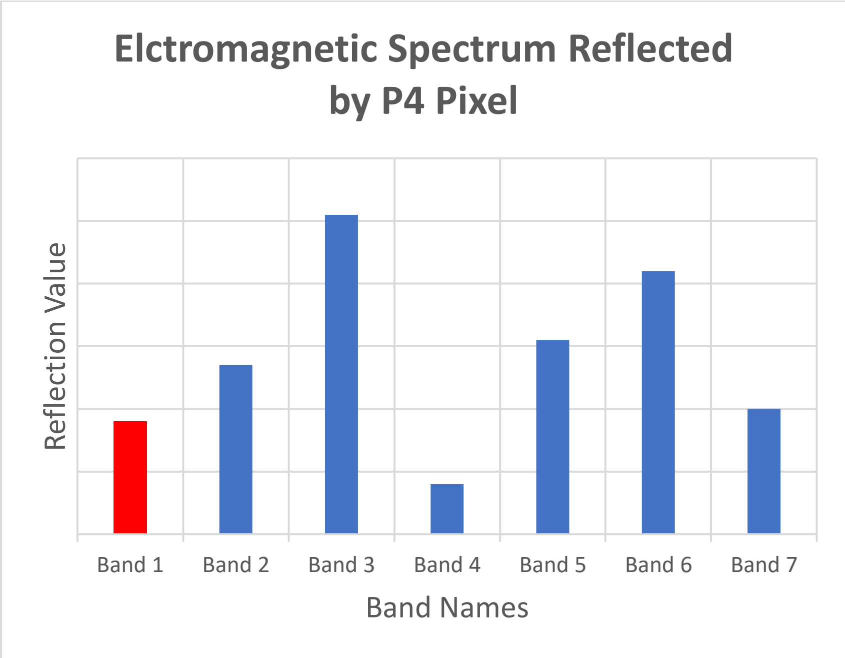
P1 = 240	P2
P3	P4



P1 = 240	P2 = 140
P3	P4



P1 = 240	P2 = 140
P3 = 120	P4

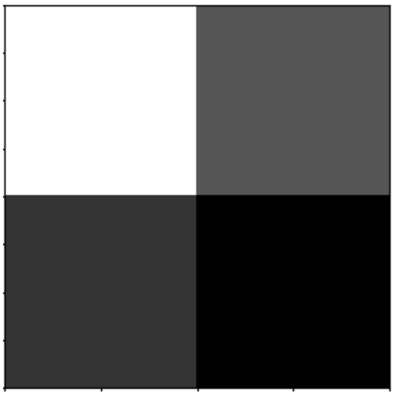


P1 = 240	P2 = 140
P3 = 120	P4 = 90

So , the final grayscale image formed by band 1 filter is :

P1 = 240	P2 = 140
P3 = 120	P4 = 90

2D array

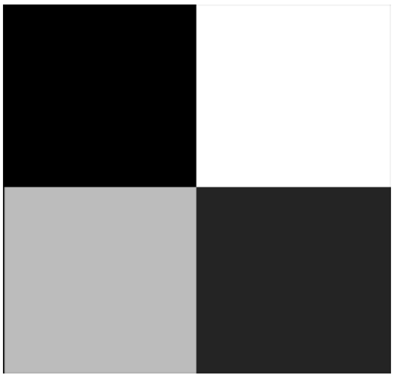


Grayscale Image

This 2D array represents the intensity value of each pixel and the image on the right side is the equivalent grayscale image of that 2D array. By this way , other grayscale image can also be formed by using other filters.

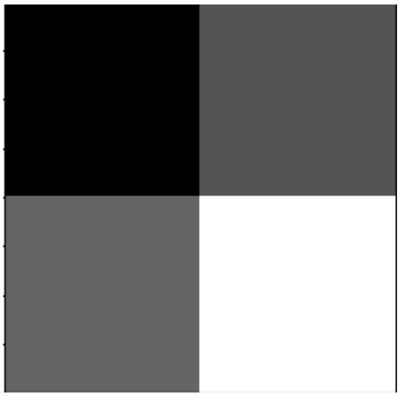
Grayscale image formed by band 2 filter is :

P1 = 124	P2 = 200
P3 = 180	P4 = 135



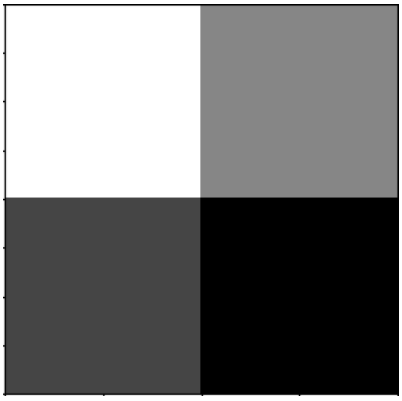
Grayscale image formed by band 3 filter is :

P1 = 98	P2 = 150
P3 = 160	P4 = 255



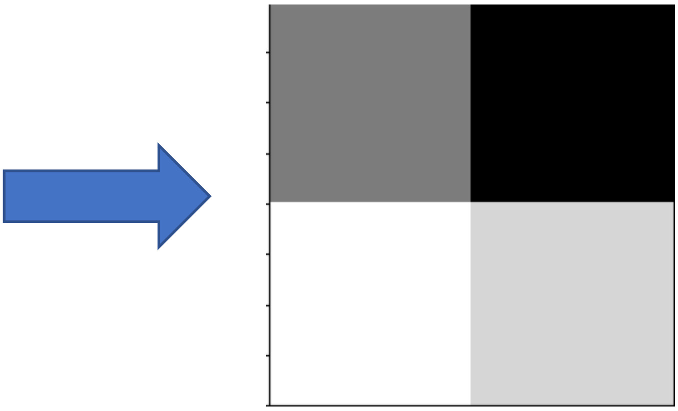
Grayscale Image formed by band 4 filter is :

P1 = 150	P2 = 98
P3 = 70	P4 = 40



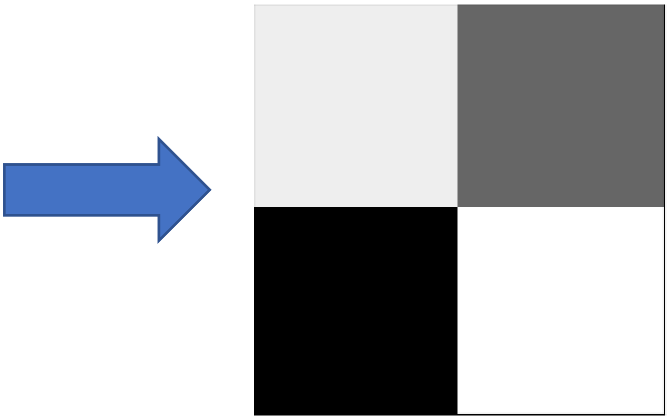
Grayscale image formed by band 5 filter is :

P1 = 100	P2 = 24
P3 = 180	P4 = 155



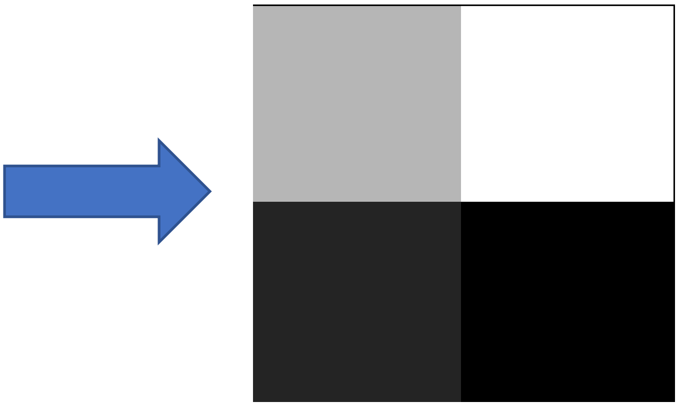
Grayscale image formed by band 6 filter is :

P1 = 200	P2 = 120
P3 = 60	P4 = 210



Grayscale image formed by band 7 filter is :

P1 = 150	P2 = 170
P3 = 110	P4 = 100



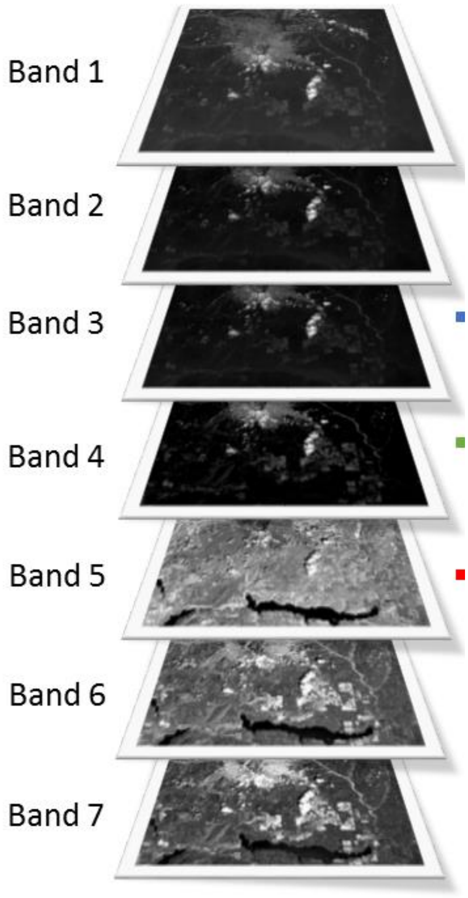
So , this is all the grayscale image of each band is formed.

The python code that was used to generate all these 7 grayscale images of corresponding 2D numeric array is :

```
from matplotlib import pyplot as plt
import numpy as np

# Set the figure size
plt.rcParams["figure.figsize"] = [7.00, 3.50]
plt.rcParams["figure.autolayout"] = True

# 2D array
data = arr = np.array([[240,140],[120,90]])

# Plot the data using imshow with gray colormap
plt.imshow(data, cmap='gray')

# Display the plot
plt.show()
```

Python code used to generate grayscale images

The gray scale image we have formed has only 4 pixel. We did it for the sake of simplicity and better understanding of how grayscale image is formed behind the scene. But in real world application , both the spatial resolution and spectral resolution is very much high. Let's look at a real example of how grayscale image with high spatial resolution and high spectral resolution looks like.



Grayscale Image

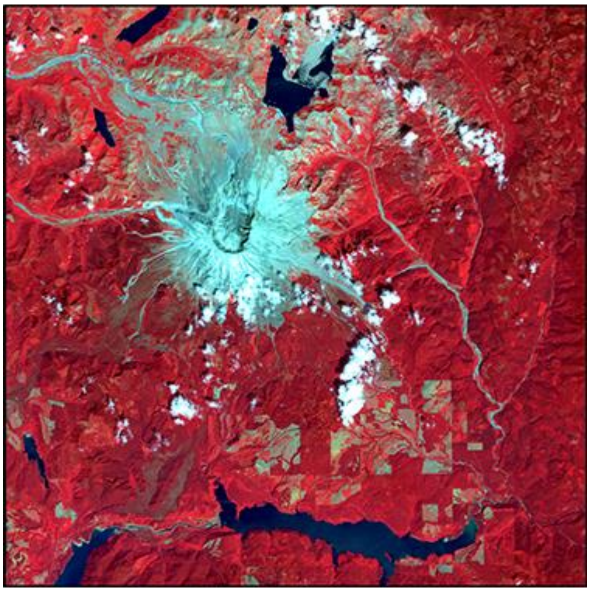
Color Composites : Sensors on earth observing satellites measure the amount of electromagnetic radiation (EMR) that is reflected or emitted from the Earth's surface. These sensors, known as multispectral sensors, simultaneously measure data in multiple regions of the electromagnetic spectrum, including visible light, near and short wave infrared. The range of wavelengths measured by a sensor is known as a band and is commonly described by the wavelength of the energy. Bands can represent any portion of the electromagnetic spectrum, including ranges not visible to the eye, such as the infrared or ultraviolet sections.

Each band of a multispectral image can be displayed one band at a time as a grey scale image, or in a combination of three bands at a time as a color composite image. The three primary colors of light are red, green, and blue. Computer screens can display an image in three different bands at a time, by using a different primary color for each band. When we combine these three images we get a color composite image.

Natural or True Color Composites : A natural or true color composite is an image displaying a combination of visible red, green and blue bands to the corresponding red, green and blue channels on the computer. The resulting composite resembles what would be observed naturally by the human eye, vegetation appears green, water dark is blue to black and bare ground and impervious surfaces appear light grey and brown. Many people prefer true color composites, as colors appear natural to our eyes, but often subtle differences in features are difficult to recognize. Natural color images can be low in contrast and somewhat hazy due the scattering of blue light by the atmosphere.

True Color

False Color Composites : False color images are a representation of a multi-spectral image produced using bands other than visible red, green and blue as the red, green and blue components of an image display. False color composites allow us to visualize wavelengths that the human eye can not see (i.e. near-infrared). Using bands such as near infra-red increases the spectral separation and often increases the interpretability of the data. There are many different false colored composites which can highlight many different features.



False Color

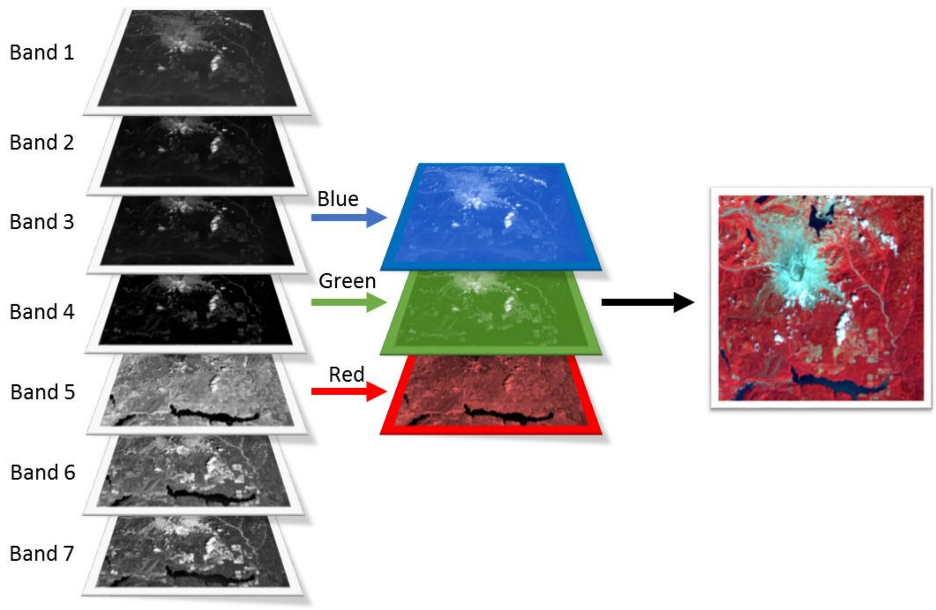
Band Combinations for Landsat 8 : Landsat 8 measures different ranges of wavelengths along the electromagnetic spectrum. Each of these ranges in known as a band and in total Landsat 8 has 11 bands. The first 7 of these bands are in the visible and infrared part of the spectrum and are commonly known as the "reflective bands" and are captured by the Operational Land Imager (OLI) on board Landsat 8. In addition to the 7 bands listed in the table to the right, there is also a panchromatic or black-and-white band (Band 8) and a cirrus cloud band (Band 9) that is used to detect cirrus clouds. Landsat 8 also has a Thermal Infrared Sensor (TIRS) which collects data in two thermal infrared bands

Let’s first look at again at table 1 where the band name , wavelength and spatial resolution of first 7 bands of Lansat – 8 were described.

Band Number	Band Name	Wavelength (nanometers)	Spatial Resolution
Band 1	Coastal Aerosol	430 – 450	30m
Band 2	Blue	450 – 510	30m
Band 3	Green	530 – 590	30m
Band 4	Red	640 – 670	30m
Band 5	Near Infrared (NIR)	850 – 880	30m
Band 6	Shortwave infrared (SWIR 1)	1570 – 1650	30m
Band 7	Shortwave infrared (SWIR 2)	2110 – 2290	30m

Color Composite Name	Red	Green	Blue
Natural Color	Band 4	Band 3	Band 2
False Color (urban)	Band 7	Band 6	Band 4
Color Infrared (vegetation)	Band 5	Band 4	Band 3
Agriculture	Band 6	Band 5	Band 2
Healthy Vegetation	Band 5	Band 6	Band 2
Land / Water	Band 5	Band 6	Band 4
Natural With Atmospheric Removal	Band 7	Band 5	Band 3
Shortwave Infrared	Band 7	Band 5	Band 4
Vegetation Analysis	Band 6	Band 5	Band 4

Band combinations are selected for a number of reasons and it is helpful to understand the spectral reflectance profiles of features you are interested in studying. For example in the NIR false color composite shown above healthy vegetation appears bright red as they reflect more near infrared than green. Another common combination uses the shortwave infrared (shown as red), the near infrared (green), and the green visible band (shown as blue). In this false color composite vegetation appear bright green, bare ground appears reddish and snow appears bright blue. Though there are many possible combinations of wavelength bands, the table to the above is a list of some that are commonly used. The band combinations are listed by band number in order of red, green, blue (RGB).



Color Infrared vegetation

Why do we use a false color composition in remote sensing?

- Human eyes could only separate up to 30 shades of gray color, so extracting information from gray-scale color visually is a bit difficult and resulting less information.

- True color composite is like watching images of what we see in real life, but for extracting detailed information such as type of vegetation, soil, or rock type becomes a bit tricky if you don’t have experience in the subject matter or sometimes it just not possible.

- Thankfully every object in this universe has unique respond to all range of a wavelength. So by recording the information from other wavelength we could identify characteristic and information of which our eyes couldn't see before, and to visualize that information we used visible wavelength (red green blue) so we could detect and see them, some combination of color resulting in a new image which really different than we usually see and highlighting new information.

vi) Information extraction and processing (V): Once the earth station receives the image data then the necessary processing includes removal of errors introduced in the information during data collection. So, after performing necessary corrections information is extracted from the images present in analog or digital form using image processing techniques.

vii) Data Analysis (W): The processed information is lastly analyzed in a proper manner to get the best suitable idea of the characteristics of objects or location under consideration. The properly analyzed information is represented in different layers of thematic maps for the purpose of simplicity in understanding. Along with that to represent the information in tabulated format quantitative measures are also considered.

So , that's all about working principle of remote sensing. Each steps in remote sensing has been described and explained in the simplest form. What I did really try in this report is to show and explain how many steps are there in remote sensing and how all these are happening with some visualization so that the idea or the concept becomes easy to understand.

Now , it's time to do some real work using Multispec software and analyze the hyperspectral image of Indian Pine Test Site and do all the operations explained throughout this report on that hyperspectral image.

220 Band AVIRIS Hyperspectral Image Data Set: June 12, 1992 Indian Pine Test Site 3

Description :

- **History →** Airborne Visible / Infrared Imaging Spectrometer (AVIRIS) hyperspectral sensor data (aviris.jpl.nasa.gov/) were acquired on June 12, 1992 over the Purdue University Agronomy farm northwest of West Lafayette and the surrounding area. The data were acquired to support soils research being conducted by Prof. Marion Baumgardner and his students.The area included major portions of the Indian Creek and Pine Creek watersheds and therefore became known as the Indian Pine data set. The AVIRIS data set include two flight lines ... one flown East-West and the other flown North - South.

- **Target Area Size →** There were three approximately **2 mile by 2 mile** 'intensive' test sites with the area that the AVIRIS data were acquired over. One in the northern portion (site 1) of the North-South flight line, one near the center (site 3) and one in the southern portion (site 2). The fields notes & photos and AVIRIS data in this publication are for site 3. Residue was a focus for the research; therefore the notes and photos document the residue condition for the fields.

- **Spatial Resolution →** Spatial resolution is the number of pixels in the target area. Or in other words , the smallest unit or the smallest area that a sensor can cover is spatial resolution. The spatial resolution of AVIRIS sensor is 20m , that means , the smallest unit this sensor can measure from target area is 20m × 20m.

- **Spectral Resolution →** Spectral resolution is the number of bands or channels or different wavelength ranges that a sensor can detect and collect from the electromagnetic spectrum. Spectral resolution of AVIRIS sensor is 220 , that means , this sensor can detect and capture 220 number of bands from electromagnetic spectrum that is reflected from target area.

- **Sensor Type →** So far , we have learnt about 2 types of sensor : multispectral sensor and hyperspectral sensor. Multispectral sensor can catch very few number of bands (like 3 to 15) from electromagnetic spectrum and hyperspectral sensor can catch way more number of bands than multispectral sensor can. Since AVIRIS sensor is able to receive 220 bands which is pretty huge in amount , this is a hyperspectral sensor.

- **Number of Filters Used →** As we discussed early that for each band , there is a particular filter. So the number of filters used in a sensor is actually the number of bands the sensor is able to detect. Since AVIRIS sensor can detect 220 bands , so the number of filter is also 220.

- **Number of Grayscale Image Formed →** In the 'Formation of Graysacle Image' section , we have come to know that for each band filter , a corresponding grayscale image of that band would be formed behind the filter. So the number of grayscale image formed is basically the number of filters used or the number of bands the sensor can catch. Since AVIRIS sensor can catch 220 bands , so 220 grayscale images would be formed in the sensor.

Band Description of AVIRIS Sensor : Since Spectral resolution of AVIRIS sensor is 220 , this sensor can detect and capture 220 number of bands , ranging from 400nm to 2500 nm , from electromagnetic spectrum that is reflected from target area. Now let’s have a look at the wavelengths of all these bands.

Calibration_Information_for_220_Channel_Data_Band_Set - Notepad

File Edit View

AVIRIS Band #	Data Channel #	Center Wavelength (nm)	FWHM (nm)	Center Uncertainty (nm)	FWHM Uncertainty (nm)
1	(not used - the band was all 0's)				
2	1	400.02	9.78	0.92	0.50
3	2	409.82	9.82	0.92	0.50
4	3	419.62	9.85	0.93	0.50
5	4	429.43	9.89	0.94	0.50
6	5	439.25	9.92	0.95	0.50
7	6	449.07	9.94	0.95	0.50
8	7	458.90	9.97	0.96	0.50
9	8	468.73	9.99	0.97	0.50
10	9	478.57	10.01	0.97	0.50
11	10	488.41	10.02	0.98	0.50
12	11	498.26	10.04	0.99	0.50
13	12	508.12	10.05	1.00	0.50
14	13	517.98	10.05	1.00	0.50
15	14	527.85	10.06	1.01	0.50
16	15	537.72	10.06	1.02	0.50
17	16	547.60	10.06	1.03	0.50
18	17	557.49	10.05	1.03	0.50
19	18	567.38	10.04	1.04	0.50
20	19	577.28	10.03	1.05	0.50
21	20	587.18	10.02	1.06	0.50
22	21	597.09	10.00	1.06	0.50
23	22	607.01	9.98	1.07	0.50
24	23	616.93	9.96	1.08	0.50
25	24	626.85	9.94	1.09	0.50
26	25	636.78	9.91	1.09	0.50
27	26	646.72	9.88	1.10	0.50
28	27	656.67	9.84	1.11	0.50
29	28	666.61	9.81	1.12	0.50
30	29	676.57	9.77	1.12	0.50
31	30	686.53	9.73	1.13	0.50
32	31	696.50	9.68	1.14	0.50
33	(not used - the band was all 0's)				
34	32	686.91	8.87	0.88	0.50
35	33	696.55	8.87	0.88	0.50
36	34	706.19	8.88	0.89	0.50
37	35	715.83	8.88	0.89	0.50
38	36	725.47	8.88	0.90	0.50
39	37	735.11	8.89	0.90	0.50
40	38	744.74	8.89	0.91	0.50
41	39	754.38	8.89	0.91	0.50
42	40	764.01	8.90	0.92	0.50
43	41	773.64	8.90	0.92	0.50
44	42	783.27	8.90	0.93	0.50
45	43	792.91	8.91	0.93	0.50
46	44	802.53	8.91	0.94	0.50
47	45	812.21	8.91	0.94	0.50
48	46	821.79	8.92	0.95	0.50
49	47	831.41	8.92	0.95	0.50
50	48	841.04	8.92	0.96	0.50
51	49	850.66	8.93	0.96	0.50
52	50	860.28	8.93	0.97	0.50
53	51	869.91	8.93	0.97	0.50
54	52	879.53	8.93	0.98	0.50
55	53	889.14	8.94	0.98	0.50
56	54	898.76	8.94	0.99	0.50
57	55	908.38	8.94	0.99	0.50
58	56	917.99	8.94	0.99	0.50

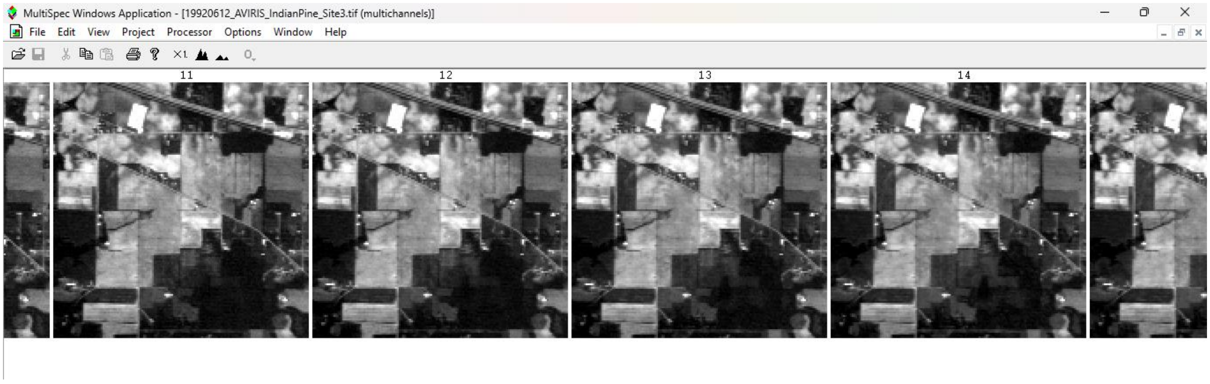
59	57	927.61	8.95	1.00	0.50
60	58	937.22	8.95	1.00	0.50
61	59	946.83	8.95	1.01	0.50
62	60	956.45	8.95	1.01	0.50
63	61	966.06	8.95	1.02	0.50
64	62	975.66	8.96	1.02	0.50
65	63	985.27	8.96	1.03	0.50
66	64	994.88	8.96	1.03	0.50
67	65	1004.48	8.96	1.04	0.50
68	66	1014.09	8.96	1.04	0.50
69	67	1023.69	8.97	1.05	0.50
70	68	1033.29	8.97	1.05	0.50
71	69	1042.89	8.97	1.06	0.50
72	70	1052.49	8.97	1.06	0.50
73	71	1062.09	8.97	1.07	0.50
74	72	1071.69	8.97	1.07	0.50
75	73	1081.29	8.97	1.08	0.50
76	74	1090.88	8.98	1.08	0.50
77	75	1100.48	8.98	1.09	0.50
78	76	1110.07	8.98	1.09	0.50
79	77	1119.66	8.98	1.10	0.50
80	78	1129.25	8.98	1.10	0.50
81	79	1138.84	8.98	1.10	0.50
82	80	1148.43	8.98	1.11	0.50
83	81	1158.02	8.98	1.11	0.50
84	82	1167.61	8.98	1.12	0.50
85	83	1177.19	8.98	1.12	0.50
86	84	1186.77	8.99	1.13	0.50
87	85	1196.36	8.99	1.13	0.50
88	86	1205.94	8.99	1.14	0.50
89	87	1215.52	8.99	1.14	0.50
90	88	1225.10	8.99	1.15	0.50
91	89	1234.68	8.99	1.15	0.50
92	90	1244.26	8.99	1.16	0.50
93	91	1253.83	8.99	1.16	0.50
94	92	1263.41	8.99	1.17	0.50
95	93	1272.98	8.99	1.17	0.50
96	94	1282.55	8.99	1.18	0.50
97	(not used - the band was all 0's)				
98	95	1273.00	9.18	1.56	0.70
99	96	1282.96	9.20	1.57	0.70
100	97	1292.93	9.22	1.57	0.70
101	98	1302.89	9.24	1.58	0.70
102	99	1312.85	9.26	1.58	0.70
103	100	1322.81	9.28	1.59	0.70
104	101	1332.77	9.30	1.59	0.70
105	102	1342.73	9.32	1.60	0.70
106	103	1352.68	9.34	1.60	0.70
107	104	1362.64	9.36	1.61	0.70
108	105	1372.59	9.37	1.61	0.70
109	106	1382.54	9.39	1.62	0.70
110	107	1392.49	9.41	1.62	0.70
111	108	1402.44	9.43	1.63	0.70
112	109	1412.39	9.44	1.63	0.70
113	110	1422.34	9.46	1.64	0.70
114	111	1432.28	9.47	1.64	0.70
115	112	1442.23	9.49	1.65	0.70
116	113	1452.17	9.51	1.65	0.70
117	114	1462.11	9.52	1.66	0.70
118	115	1472.05	9.54	1.66	0.70
119	116	1481.99	9.55	1.67	0.70
120	117	1491.92	9.57	1.67	0.70
121	118	1501.86	9.58	1.68	0.70
122	119	1511.79	9.59	1.68	0.70
123	120	1521.73	9.61	1.69	0.70
124	121	1531.66	9.62	1.69	0.70
125	122	1541.59	9.63	1.70	0.70
126	123	1551.52	9.65	1.70	0.70
127	124	1561.44	9.66	1.71	0.70
128	125	1571.37	9.67	1.71	0.70
129	126	1581.30	9.68	1.72	0.70
130	127	1591.22	9.70	1.72	0.70
131	128	1601.14	9.71	1.73	0.70
132	129	1611.06	9.72	1.73	0.70
133	130	1620.98	9.73	1.74	0.70
134	131	1630.90	9.74	1.74	0.70
135	132	1640.81	9.75	1.75	0.70
136	133	1650.73	9.76	1.75	0.70
137	134	1660.64	9.77	1.76	0.70
138	135	1670.56	9.78	1.77	0.70
139	136	1680.47	9.79	1.77	0.70
140	137	1690.38	9.80	1.78	0.70
141	138	1700.28	9.81	1.78	0.70
142	139	1710.19	9.82	1.79	0.70
143	140	1720.10	9.82	1.79	0.70
144	141	1730.00	9.83	1.80	0.70
145	142	1739.90	9.84	1.80	0.70
146	143	1749.81	9.85	1.81	0.70
147	144	1759.71	9.85	1.81	0.70
148	145	1769.60	9.86	1.82	0.70
149	146	1779.50	9.87	1.82	0.70
150	147	1789.40	9.87	1.83	0.70

151	148	1799.29	9.88	1.83	0.70
152	149	1809.19	9.89	1.84	0.70
153	150	1819.08	9.89	1.84	0.70
154	151	1828.97	9.90	1.85	0.70
155	152	1838.86	9.90	1.85	0.70
156	153	1848.75	9.91	1.86	0.70
157	154	1858.63	9.91	1.86	0.70
158	155	1868.52	9.91	1.87	0.70
159	156	1878.40	9.92	1.87	0.70
160	157	1888.28	9.92	1.87	0.70
161	(not used - the band was all 0's)				
162	158	1883.24	13.72	2.25	1.85
163	159	1893.25	13.75	2.25	1.85
164	160	1903.26	13.79	2.26	1.85
165	161	1913.26	13.82	2.26	1.85
166	162	1923.27	13.85	2.27	1.85
167	163	1933.27	13.88	2.28	1.85
168	164	1943.27	13.91	2.28	1.85
169	165	1953.26	13.95	2.29	1.85
170	166	1963.25	13.97	2.29	1.85
171	167	1973.24	14.00	2.30	1.85
172	168	1983.23	14.03	2.31	1.85
173	169	1993.22	14.06	2.31	1.85
174	170	2003.20	14.09	2.32	1.85
175	171	2013.18	14.11	2.32	1.85
176	172	2023.16	14.14	2.33	1.85
177	173	2033.13	14.16	2.34	1.85
178	174	2043.10	14.19	2.34	1.85
179	175	2053.07	14.21	2.35	1.85
180	176	2063.04	14.23	2.35	1.85
181	177	2073.00	14.26	2.36	1.85
182	178	2082.97	14.28	2.37	1.85
183	179	2092.92	14.30	2.37	1.85
184	180	2102.88	14.32	2.38	1.85
185	181	2112.83	14.34	2.38	1.85
186	182	2122.78	14.36	2.39	1.85
187	183	2132.73	14.38	2.40	1.85
188	184	2142.68	14.39	2.40	1.85
189	185	2152.62	14.41	2.41	1.85
190	186	2162.56	14.43	2.41	1.85
191	187	2172.50	14.44	2.42	1.85
192	188	2182.43	14.46	2.43	1.85
193	189	2192.37	14.47	2.43	1.85
194	190	2202.30	14.49	2.44	1.85
195	191	2260.22	14.50	2.44	1.85
196	192	2270.15	14.51	2.45	1.85
197	193	2232.07	14.52	2.46	1.85
198	194	2241.99	14.53	2.46	1.85
199	195	2251.90	14.54	2.47	1.85
200	196	2261.82	14.55	2.47	1.85
201	197	2271.73	14.56	2.48	1.85
202	198	2281.64	14.57	2.49	1.85
203	199	2291.54	14.58	2.49	1.85
204	200	2301.45	14.58	2.50	1.85
205	201	2311.35	14.59	2.50	1.85
206	202	2321.25	14.60	2.51	1.85
207	203	2331.14	14.60	2.52	1.85
208	204	2341.03	14.61	2.52	1.85
209	205	2350.92	14.61	2.53	1.85
210	206	2360.81	14.61	2.53	1.85
211	207	2370.70	14.61	2.54	1.85
212	208	2380.58	14.61	2.55	1.85
213	209	2390.46	14.62	2.55	1.85
195	191	2260.22	14.50	2.44	1.85
196	192	2270.15	14.51	2.45	1.85
197	193	2232.07	14.52	2.46	1.85
198	194	2241.99	14.53	2.46	1.85
199	195	2251.90	14.54	2.47	1.85
200	196	2261.82	14.55	2.47	1.85
201	197	2271.73	14.56	2.48	1.85
202	198	2281.64	14.57	2.49	1.85
203	199	2291.54	14.58	2.49	1.85
204	200	2301.45	14.58	2.50	1.85
205	201	2311.35	14.59	2.50	1.85
206	202	2321.25	14.60	2.51	1.85
207	203	2331.14	14.60	2.52	1.85
208	204	2341.03	14.61	2.52	1.85
209	205	2350.92	14.61	2.53	1.85
210	206	2360.81	14.61	2.53	1.85
211	207	2370.70	14.61	2.54	1.85
212	208	2380.58	14.61	2.55	1.85
213	209	2390.46	14.62	2.55	1.85
214	210	2400.33	14.62	2.56	1.85
215	211	2410.21	14.62	2.56	1.85
216	212	2420.08	14.61	2.57	1.85
217	213	2429.95	14.61	2.58	1.85
218	214	2439.81	14.61	2.58	1.85
219	215	2449.68	14.61	2.59	1.85
220	216	2459.54	14.60	2.59	1.85
221	217	2469.40	14.60	2.60	1.85
222	218	2479.25	14.59	2.61	1.85
223	219	2489.11	14.59	2.61	1.85
224	220	2498.96	14.58	2.62	1.85

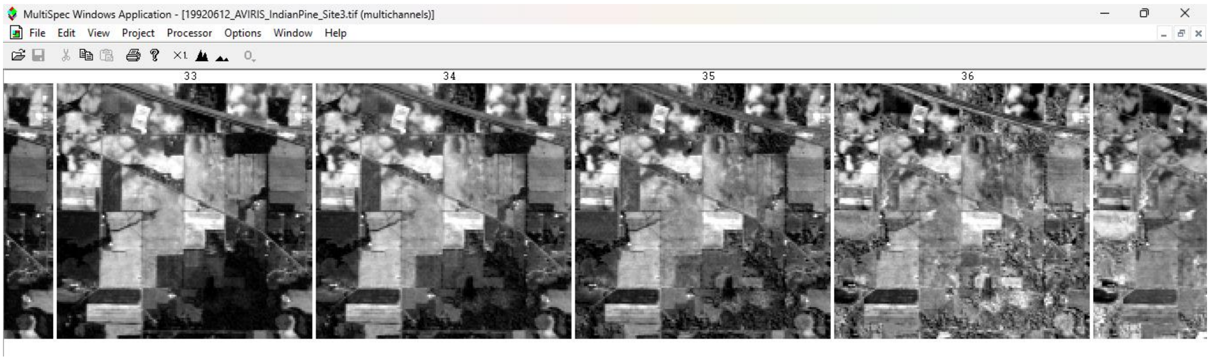
Grayscale Image of Indian Pine Test Site 3 formed in AVIRIS Sensor :

As we have already known that the spectral resolution of AVIRIS sensor is 220 and the number of grayscale image formed in sensor is as same as the spectral resolution,so 220 grayscale images will be formed for each band in the sensor.Let's look at some grayscale images of Indian Pine Test Site 3 using multispec windows software.

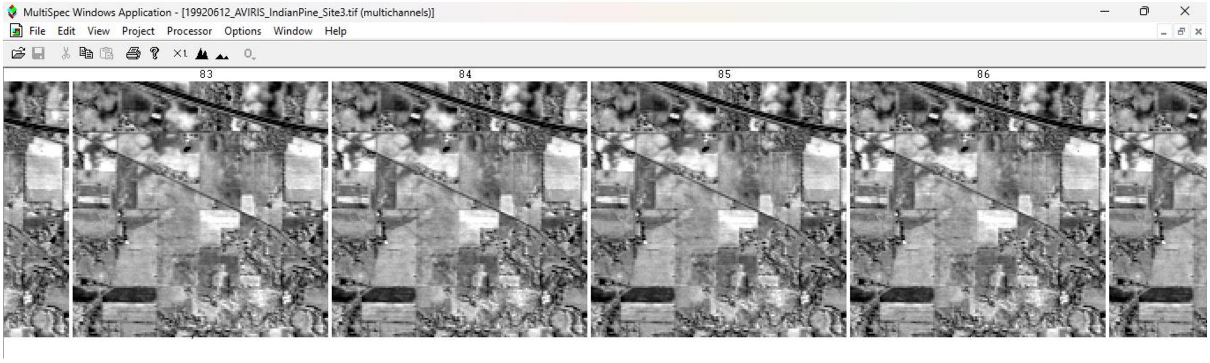
Band 1,2,3,4,5



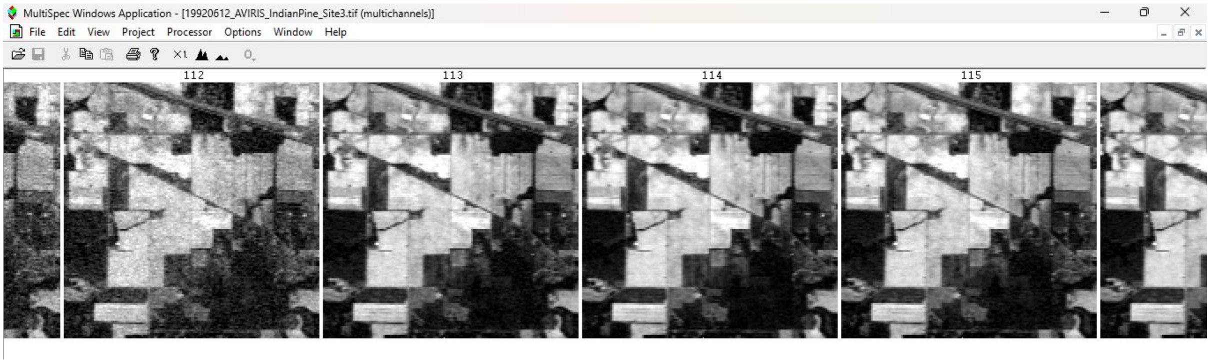
Band 11,12,13,14



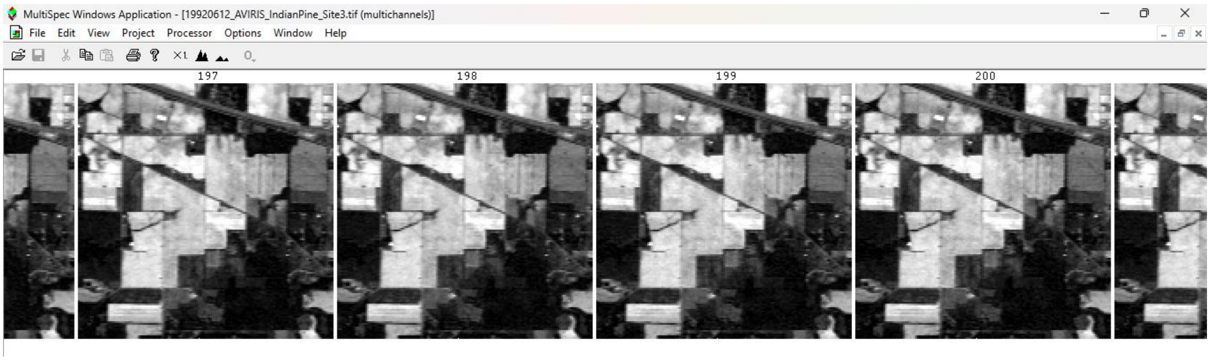
Band 33,34,35,36



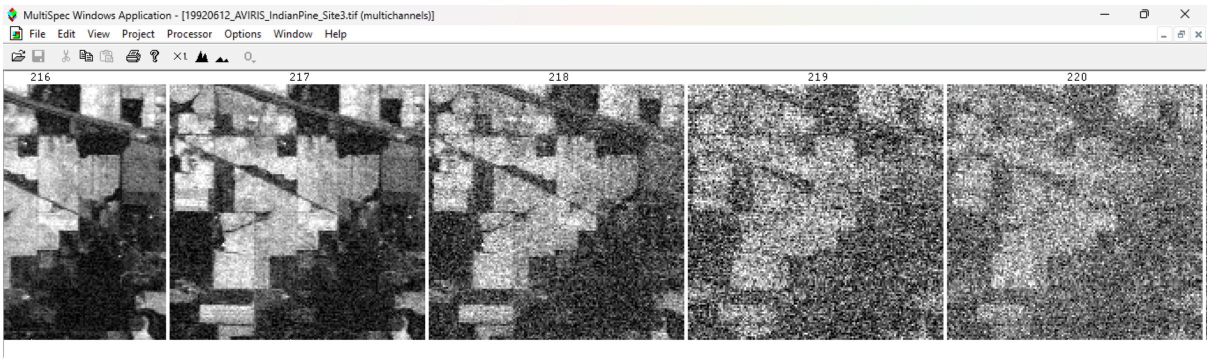
Band 83,84,85,86



Band 112,113,114,115



Band 197,198,199,200

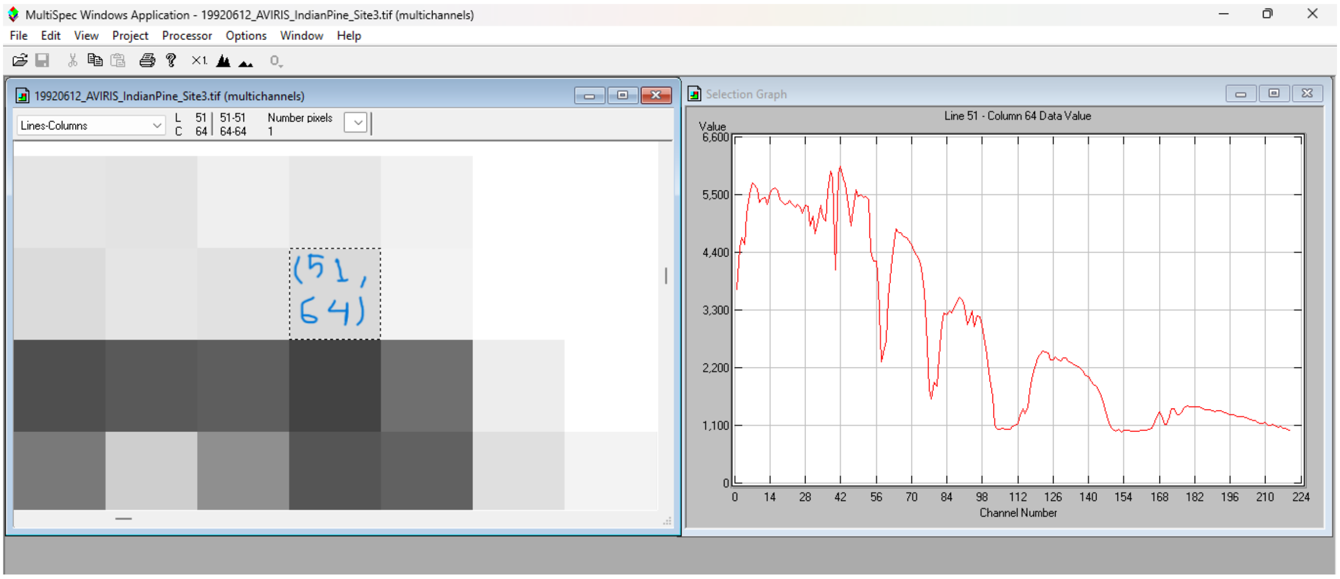


Band 216,217,218,219,220

Selection Graph : Selection graph is the visual representation of reflection value or intensity value of each bands by a single pixel from the target area. In multispec software , there is an option for selection graph where we can select any single pixel or multiple pixel and see the reflection value or intensity value of each bands by that pixel(s).

This AVIRIS image file represents a 2 mile × 2 mile area at 20 meters spatial resolution and consists of 145 ×145 pixels.

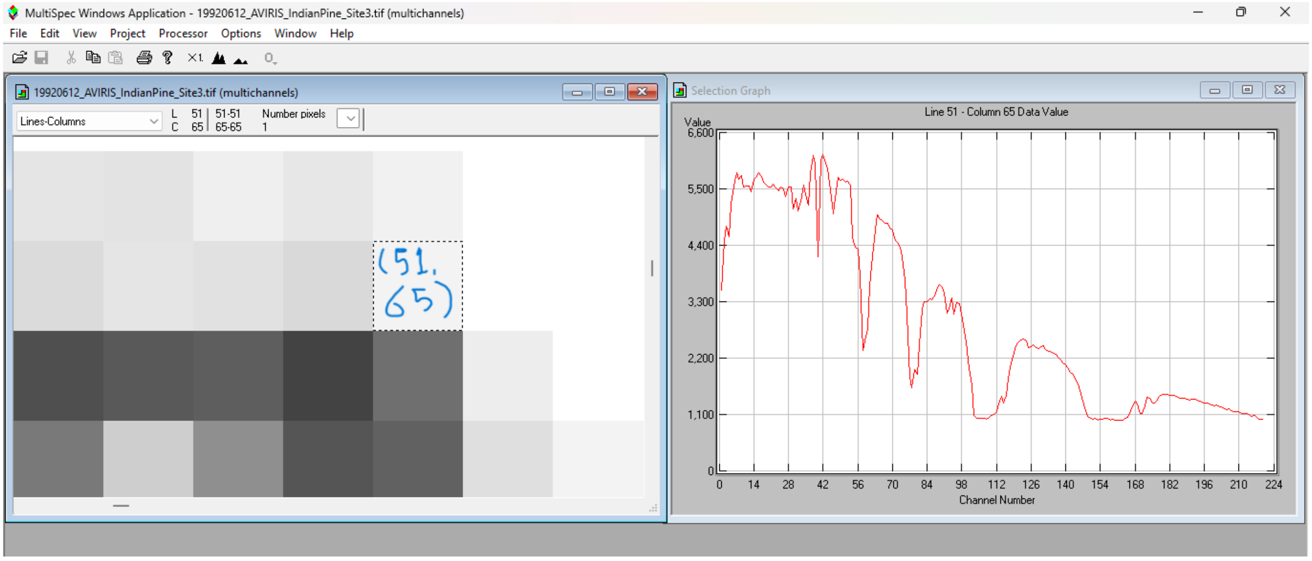
Let's look at the pixel located at (Line,Column) = (51,64).



From this graph it is seen that the (51,64) pixel has

- A great rising reflectance value at the beginning from band no 0 to approximately band no 10.
- The maximum reflectance value at band no approximately 42.
- The minimum reflectance value at band no approximately 100.

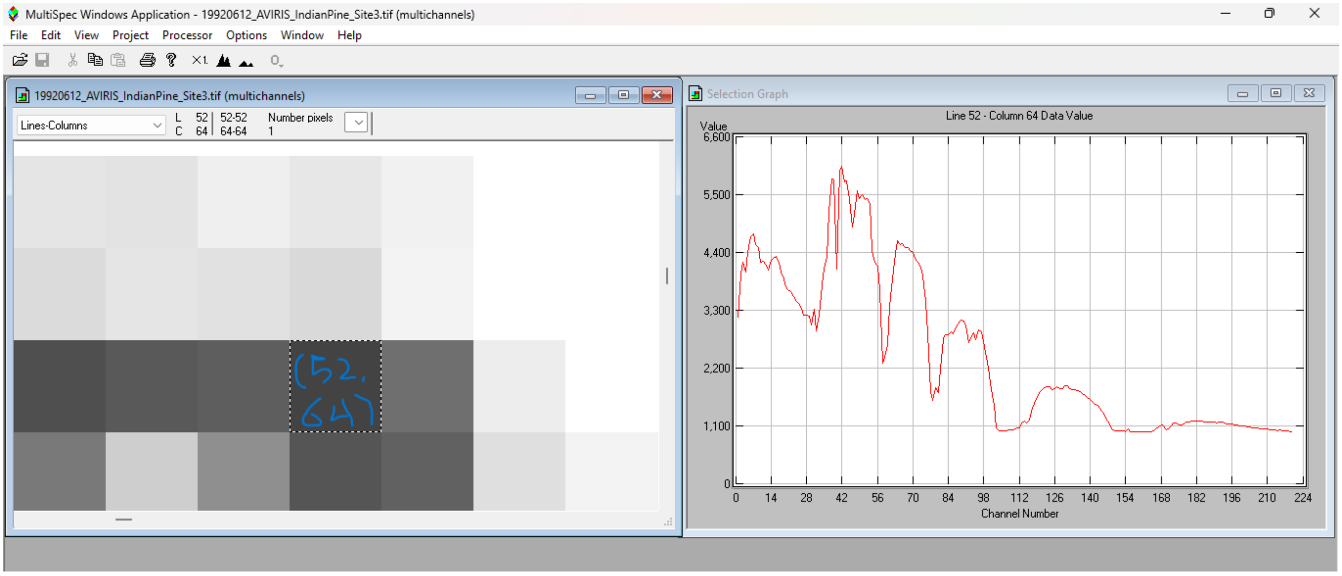
Let’s look at the pixel located at (Line,Column) = (51,65).



From this graph it is seen that the (51,65) pixel has

- Almost as same curve as the one from (51,64) but kind of shifted up
- The maximum reflectance value at band no approximately 38 and 42.
- The minimum reflectance value at band no 100.

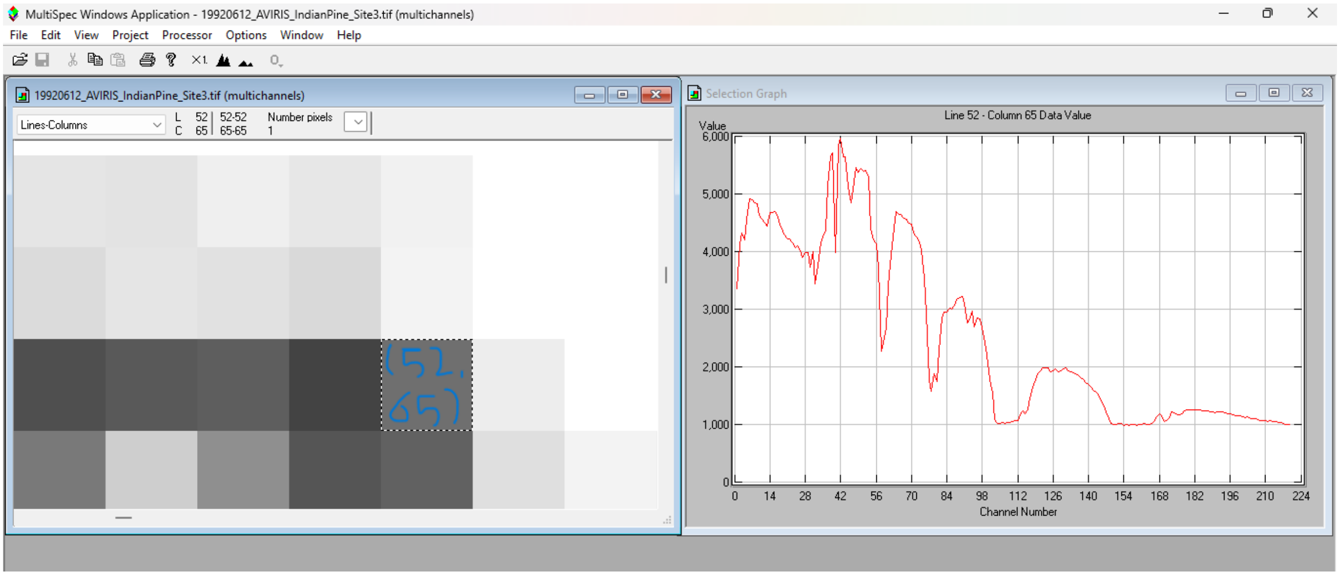
Let’s look at the pixel located at (Line,Column) = (52,64).



From this graph it is seen that the (52,64) pixel has

- Comparatively less reflectance value than previous curves
- The maximum reflectance value at band no approximately 42.
- The minimum reflectance value at band no approximately 100.

Let’s look at the pixel located at (Line,Column) = (52,65).



From this graph it is seen that the (52,65) pixel has

- Kind of similar curve compared to the one from (52,64) but lifted up slightly
- The maximum reflectance value at band no approximately 42
- The minimum reflectance value at band no approximately 100.

Color Composites : Each band of a multispectral image can be displayed one band at a time as a grey scale image, or in a combination of three bands at a time as a color composite image. The three primary colors of light are red, green, and blue. Computer screens can display an image in three different bands at a time, by using a different primary color for each band. When we combine these three images we get a color composite image.

Let's look at some basic combinations in color composites :

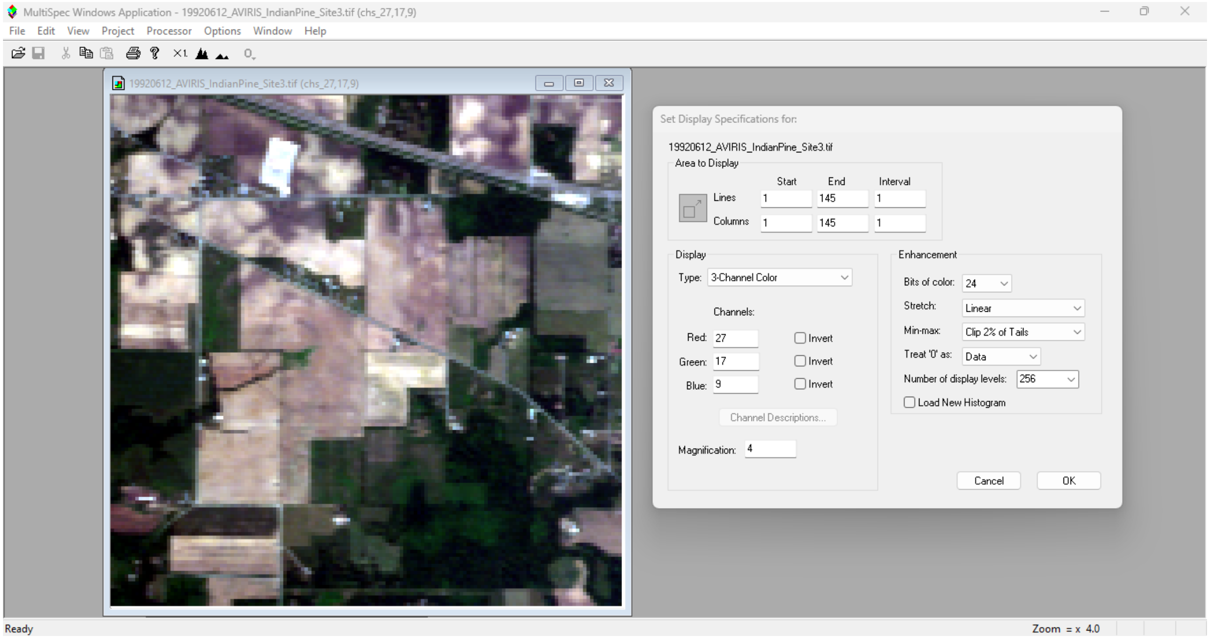
Color Composite Name	Red	Green	Blue
Natural Color	Red (640-670)	Green (530-590)	Blue (450-510)
False Color (urban)	SWIR 2 (2110-2290)	SWIR 1 (1570-1650)	Red (640-670)
Color Infrared (vegetation)	NIR (850-880)	Red (640-670)	Green (530-590)
Agriculture	SWIR 1 (1570-1650)	NIR (850-880)	Blue (450-510)
Healthy Vegetation	NIR (850-880)	SWIR 1 (1570-1650)	Blue (450-510)
Land / Water	NIR (850-880)	SWIR 1 (1570-1650)	Red (640-670)
Natural With Atmospheric Removal	SWIR 2 (2110-2290)	NIR (850-880)	Green (530-590)
Shortwave Infrared	SWIR 2 (2110-2290)	NIR (850-880)	Red (640-670)
Vegetation Analysis	SWIR 1 (1570-1650)	NIR (850-880)	Red (640-670)

Since there are multiple bands lying in Red , Green , Blue , NIR , SWIR 1 and SWIR 2 region , so let's take one band from each region.

Region Name	Band no
Red	27
Green	17
Blue	9
Near Infraed (NIR)	51
Shortwave Infrared (SWIR 1)	129
Shortwave Infrared (SWIR 2)	190

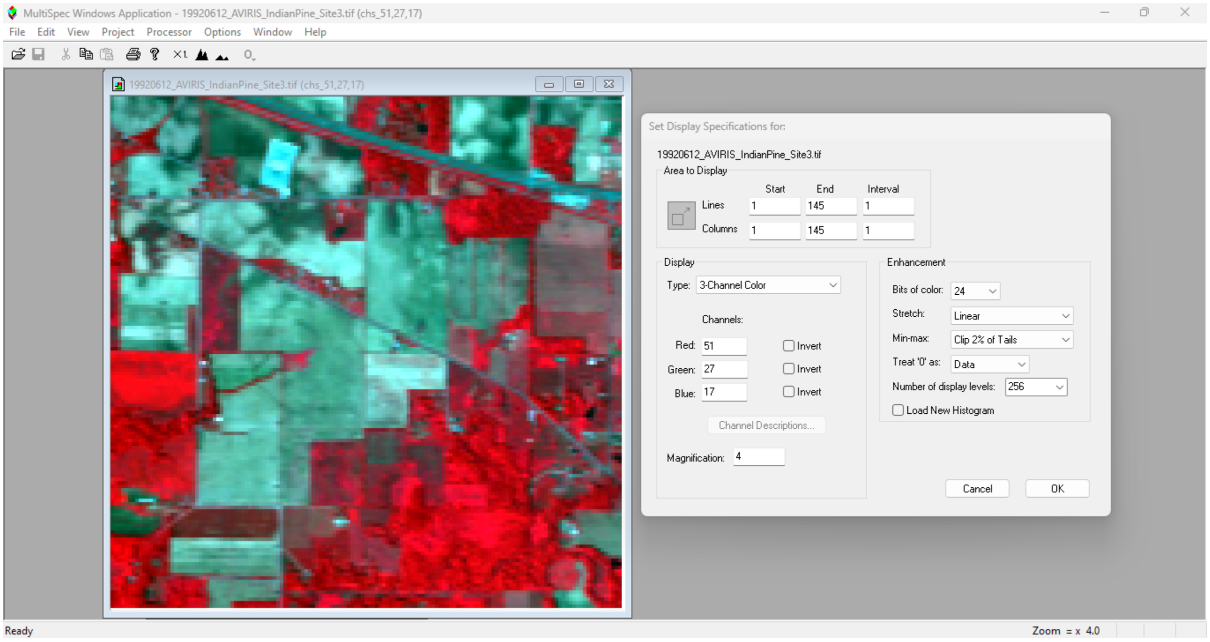
<u>Natural Color Composite :</u>

Red	Green	Blue
27	17	9



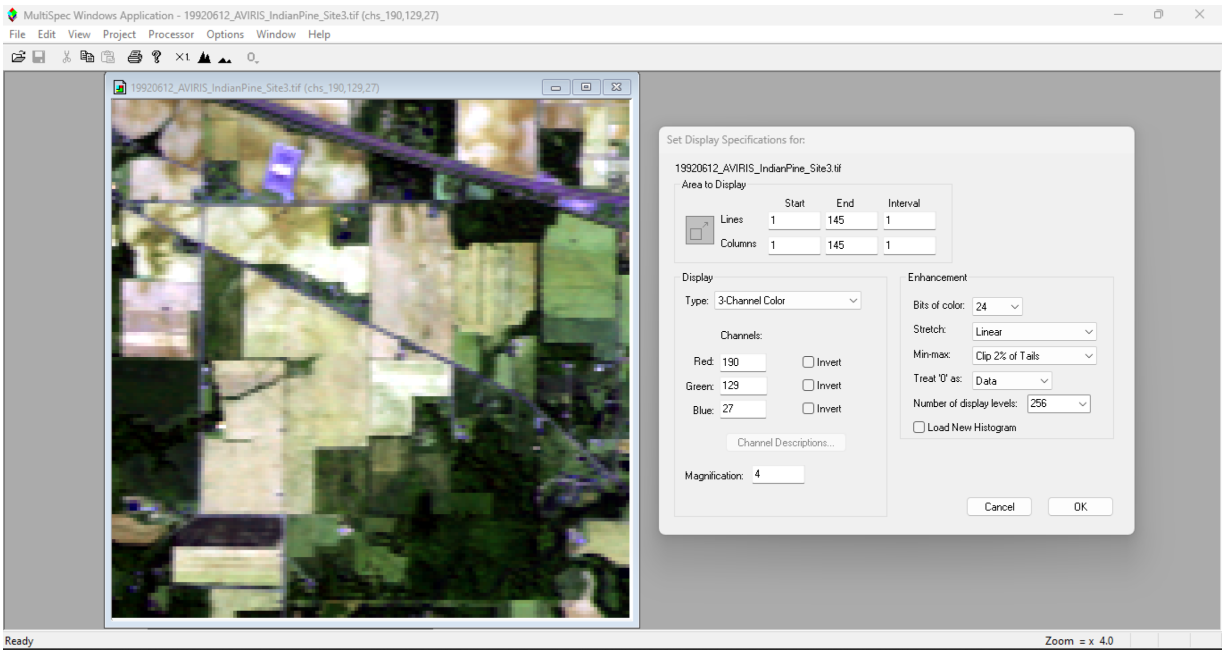
Color Infrared (vegetation) :

Red	Green	Blue
51	27	17



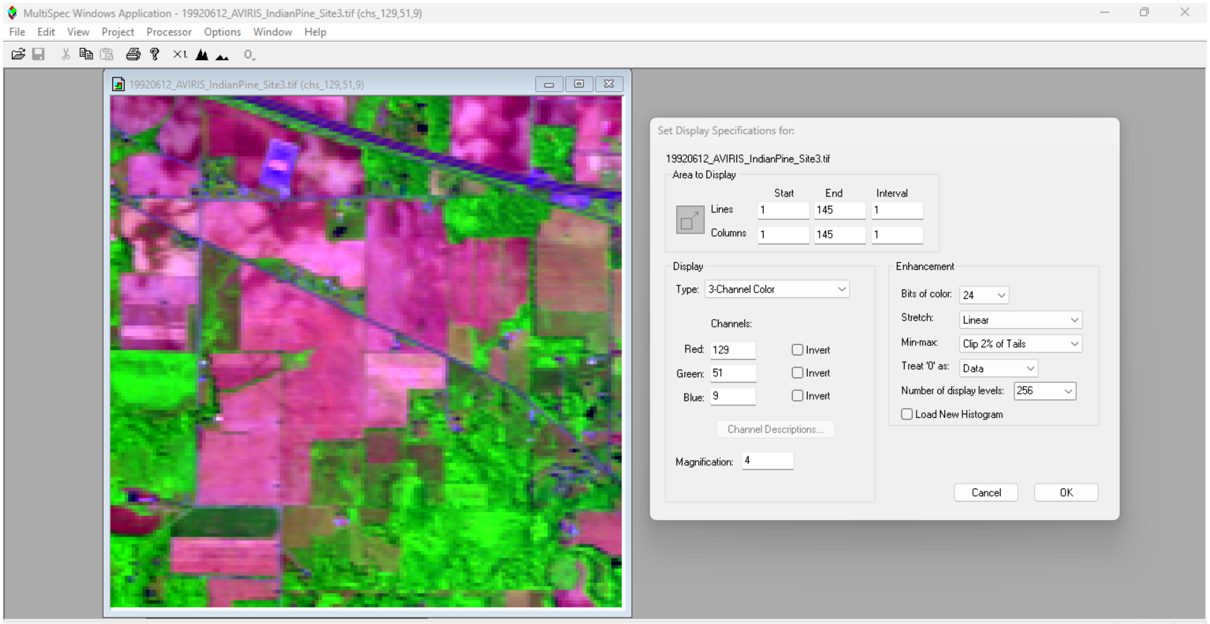
False Color (urban) :

Red	Green	Blue
190	129	27



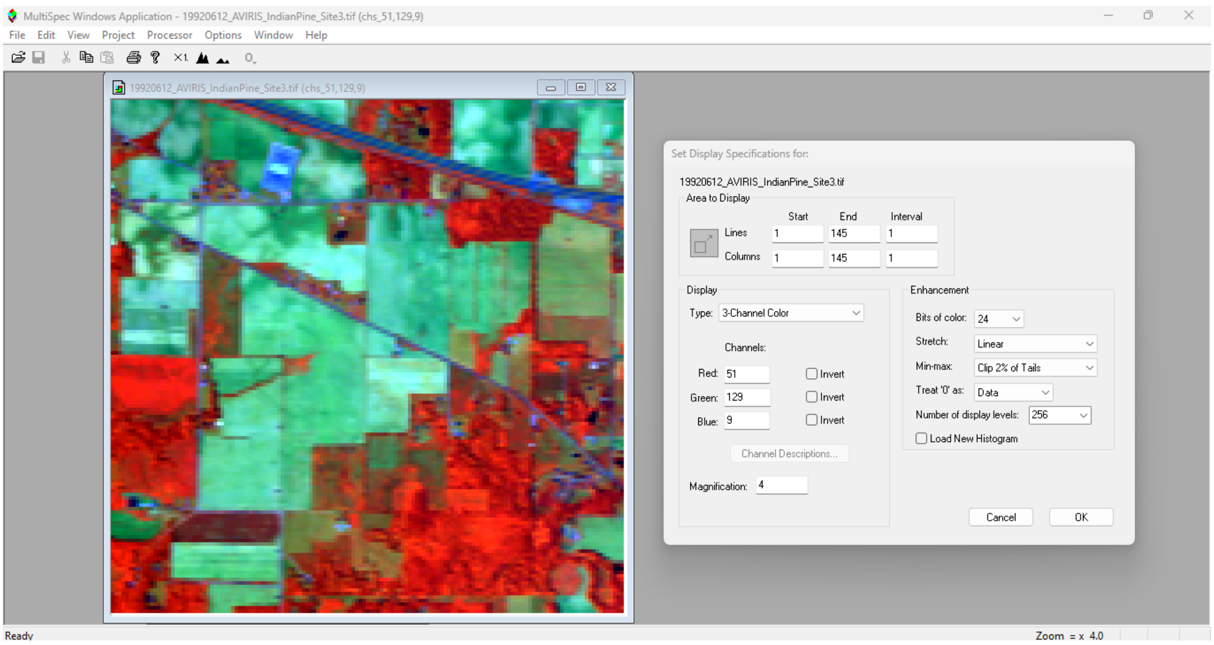
Agriculture :

Red	Green	Blue
129	51	9



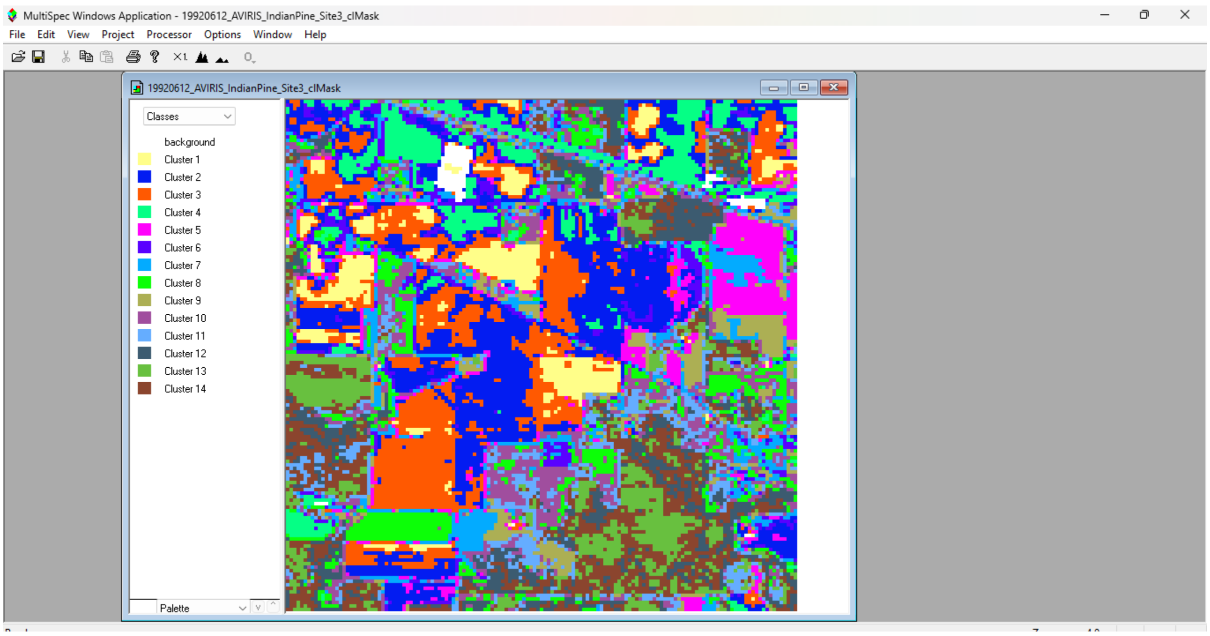
Healthy Vegetation :

Red	Green	Blue
51	129	9



Unsupervised classification of Hyperspectral Image for Indian Pine Test Site 3

Unsupervised classification is where the outcomes (groupings of pixels with common characteristics) are based on the software analysis of an image without the user providing sample classes. The computer uses techniques to determine which pixels are related and groups them into classes. The user can specify which algorism the software will use and the desired number of output classes but otherwise does not aid in the classification process. However, the user must have knowledge of the area being classified when the groupings of pixels with common characteristics produced by the computer have to be related to actual features on the ground (such as wetlands, developed areas, coniferous forests, etc.).



Unsupervised Classification