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Satellite Software Development: Remote Sensing and Image Processing

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Abstract: **Standard digital cameras are designed to replicate what is seen in the human eye, as they capture light only in the red, green and blue (RGB) wavelengths. Filters are then applied to these wavelengths to generate a natural looking RGB image. On the other hand, using remote sensing from sensor systems in satellites, we can capture multispectral images and extract information a human eye fails to see.**

Keywords: **Satellite Software Development, Remote Sensing, Image Processing, Band Combination, Algorithms, Spectral Reflectance.**

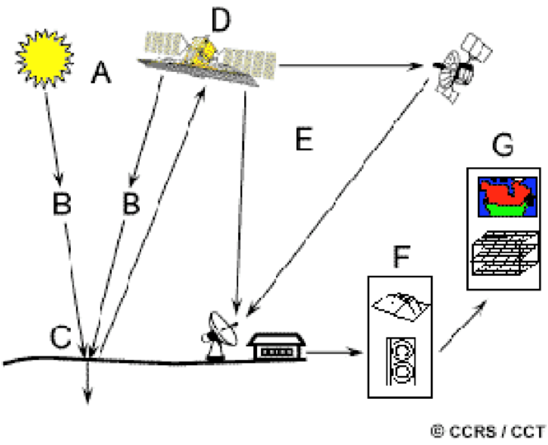
I. INTRODUCTION

Standard digital cameras are designed to replicate what is seen in the human eye, as they capture light only in the red, green and blue (RGB) wavelengths. Filters are then applied to these wavelengths to generate a natural looking RGB image. On the other hand, using remote sensing from sensor systems in satellites, we can capture multispectral image and extract additional information a human eye fails to see. A multispectral image captures data within particular wavelength ranges across the electromagnetic spectrum. Filters or instruments are then used to separate wavelengths that are perceptive to other specific wavelengths, for example we can separate frequencies beyond the visible light range, such as infrared and ultra-violet.

II. REMOTE SENSING

Remote sensing refers to the use of satellite-based sensor technologies to detect and classify objects based on electromagnetic radiation. Sensors on board satellites read amounts of reflected energy transmitted to them from the atmosphere, lands, and oceans. This data is then stored and converted to picture format. The process can be illustrated in Fig. I below.

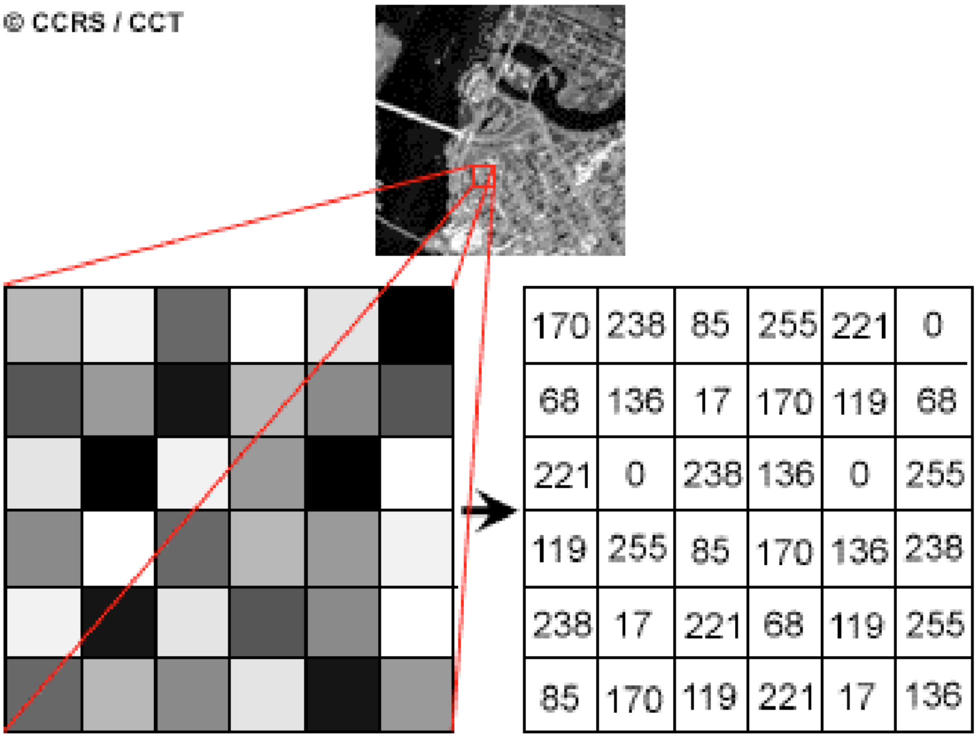
Fig. I



Remote sensing process

Similar to the images on our television set, satellite imagery is composed of tiny squares, each of a distinctive gray shade or color, these squares are called pixels. Each pixel represents the intensity of the energy detected for a given area, as we can see in figure II. Sensors electronically record electromagnetic energy as an array of numbers in digital format.

Fig. II



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

Each pixel represents the intensity of the light detected

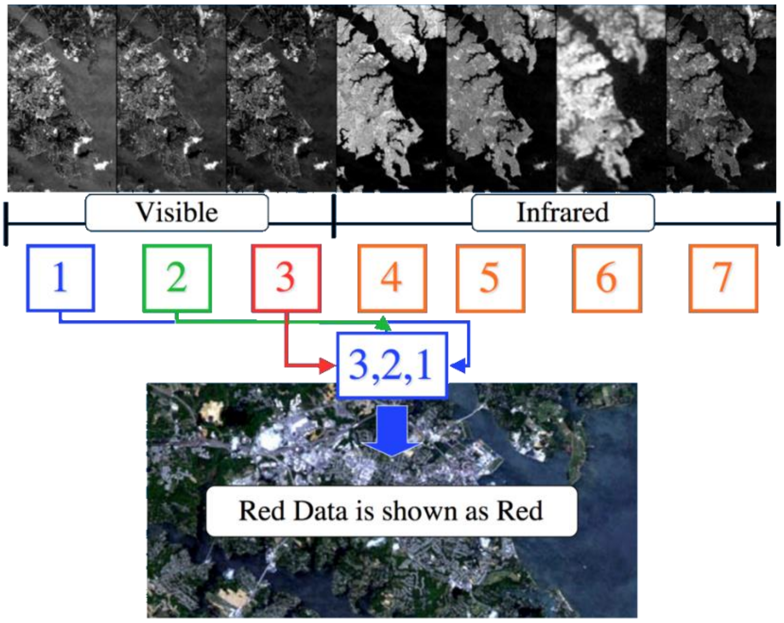
For instance, in the Landsat 7 satellite, the sensor processes the amount of reflected energy for each 30mX30m area. Each band of data provides an amount of energy reflected in a particular range of the electromagnetic spectrum. For example, band 4 measures the intensity of the near-infrared energy reflected, and Band 2 measures the intensity of red light indicated. Thus, for each pixel in each band of data, there is a numerical value given to the amount of energy reflected from the planet's surface for that 30X30 meter square.

From these numerical values, we can develop a software program such as Geographic Information Systems (GIS), which is a tool that analyzes, stores, manipulates and visualizes geographic data, and write algorithms to quantify ground cover and land use from the given information. In turn, we can examine many aspects of our planet such as forest fires, diseases, agribusiness, flood predictions, etc. This information is not achievable with conventional photographs.

III. BAND COMBINATION

Moreover, to better understand the information, humans need visual representations of these data, since the human eye is not sensitive to wavelengths such as ultraviolet or infrared light. To construct a composite image from remote sensing data that makes sense to our eyes, we must utilize the colors that are from the visible portion of the EMS, which are red, green, and blue. Hence, to construct a readable image, the numeric scale will be converted to a specific color. Therefore, we can assign a color for each band of the data, such that it replaces the shades of black and white to shades of red. To illustrate, Figure 5 shows a Landsat scene. Notice that all seven bands of data are initially in greyscale, even those that denote visible portions of the spectrum, blue, green or red reflected light. Now we can assign a color to the data. We assigned the color blue to the band representing the blue light, the color green to the band representing the green light, and red to the band of data representing the red light. This develops a "true color" image.

Fig. III

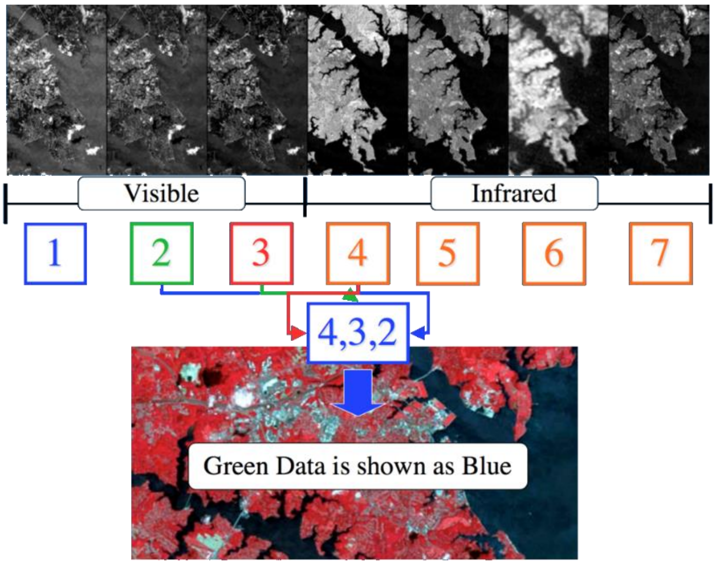


Landsat 7 'Natural Color' band composition

Figure 6 shows another example composing a "false color" image, in 4,3,2 combinations. Band 4, the near-infrared, is assigned the color red. Band 3, representing light reflecting in the red portion of the spectrum, is allocated the color green, and band 2, representing light reflecting in the green portion of the spectrum, is assigned the color blue.

To explain the previous assignments, we mentioned previously that healthy vegetation reflects strongly in the near infra-red. If we assign the vegetation to the color red, our eyes will detect it. In a "false color" image, the turquoise color indicates the manufactured environment such as roads, pavement, and buildings. And black or dark blue indicates water or cloud shadows.

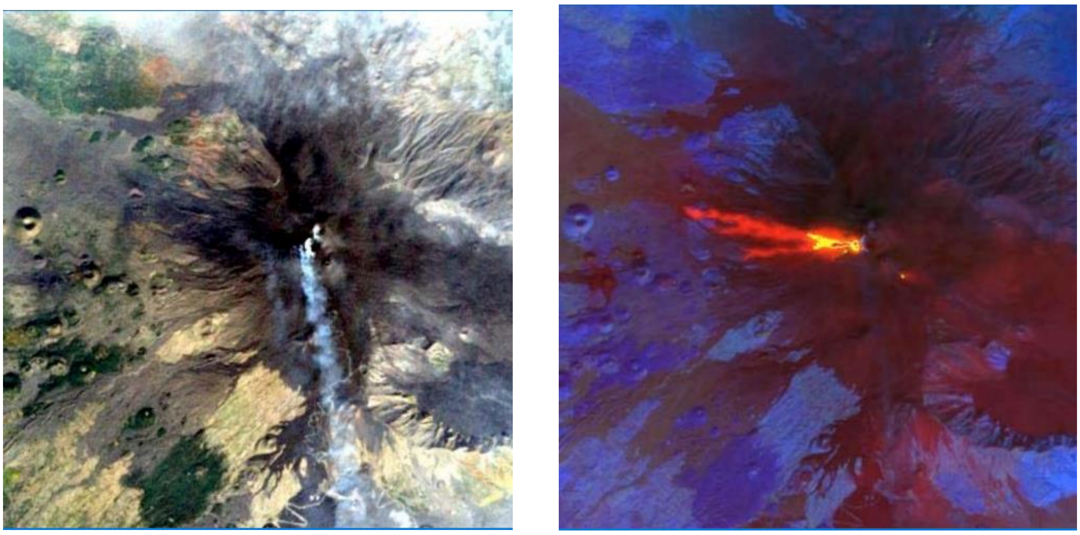
Fig. IV



Landsat 7 'False Color' band composition

In figure 7 below, we can see a comparison of Mount Etna erupting between the natural image in (a), visible light, and the customized band combination of (b), using infra-red light. We can see the importance of using more than one kind of band combination, as the volcano eruption is not shown clearly in the natural image.

Fig. V



a) Bands 3,2,1 (visible light) *b) Bands 6,5,4 (infrared light)*

Visual comparison between different band combinations

Manually combining different bands to construct a clear image cannot be done in an efficient matter. Thus, Image processing applications are required to visualize these multispectral images, which are generated using three spectral bands of data. In the platform, a user can choose to use any number of bands and combines them to create a color composite image. A satellite image is much more than a picture. Each pixel has a numeric representation of the amount of energy reflected in each of three designated wavelengths; this information can be used to make numerous measurements [4].

Some band combinations need to be calculated to preform further analysis. We will discuss how to calculate two major land cover groups, vegetation and water bodies, using the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI).We can use only four bands (Green, Red, NIR, SWIR). Landsat 8 and 7 data's bands, wavelength and their resolution are shown in the figure below.

Fig. VI

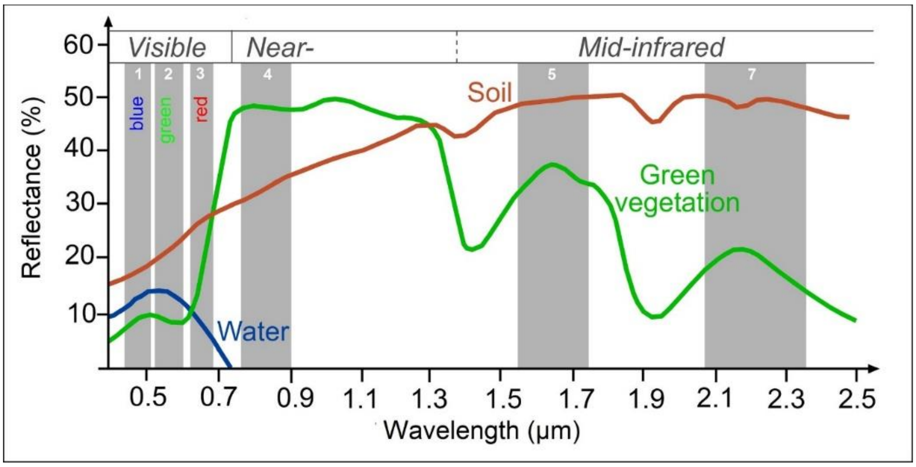
S.N.	Landsat 7 Enhanced Thematic Mappers Plus (ETM +)			Band	Landsat 8 Operational Land Imagers (OLI) & Thermal Infrared Sensor (TIRS)		
	Resolution (meter)	**Wavelength (micrometer)**	**Band Name**		**Band Name**	**Wavelength (micrometers)**	**Resolution (meter)**
1	30	0.45-0.52	Blue	**Band 1**	Ultra-Blue	0.435-0.451	30
2	30	0.52-0.60	Green	**Band 2**	Blue	0.452-0.512	30
3	30	0.63-0.69	Red	**Band 3**	Green	0.533-0.590	30
4	30	0.77-0.90	NIR	**Band 4**	Red	0.636-0.673	30
5	30	1.55-1.75	SWIR 1	**Band 5**	NIR	0.851-0.879	30
6	60* (30)	10.40-12.50	Thermal	**Band 6**	SWIR 1	1.566-1.651	30
7	30	2.09-2.35	SWIR 2	**Band 7**	SWIR 2	2.107-2.294	30
8	15	0.52-0.90	Panchromatic	**Band 8**	Panchromatic	0.503-0.676	15
9				**Band 9**	Cirrus	1.363-1.384	30
10				**Band 10**	TIRS 1	10.60-11.19	100 * (30)
11				**Band 11**	TIRS 2	11.50-12.51	100 * (30)

IV. SPECTRAL REFLECTANCE

Different surface characteristics reflect the sun's electromagnetic radiation in different ways. The reflectance features of an object depend on the material and its chemical and physical nature, such as the surface roughness and the geometric circumstances (incidence angle of the sunlight). Also, the reflectance of an object differs with the wavelength of the electromagnetic energy. These variations in reflectance help to recognize complex earth surface features. We can analyze their spectral reflectance properties through spectral reflectance curves, which graph the spectral reflectance of objects as a function of wavelengths. This curve can visualize the formula of NDVI and other indexes.

Humboldt State University. Spectral Reflectance. Retrieved from http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson2-1/reflectance.html

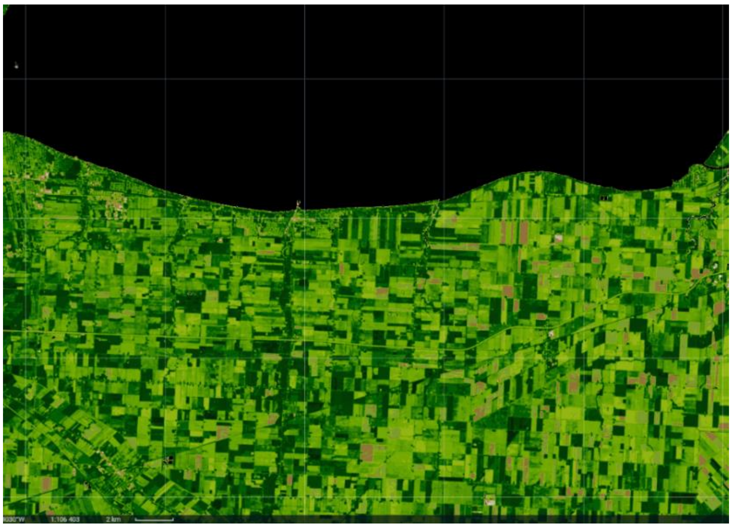
Fig. VII



Spectral Reflectance Curve

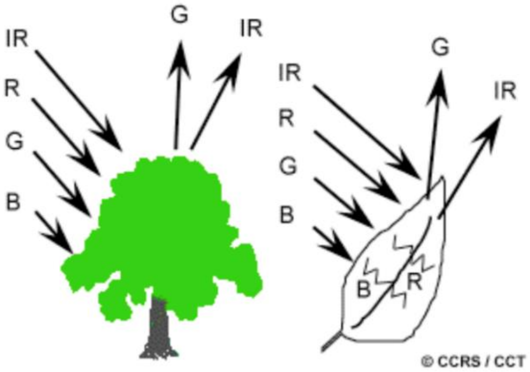
Normalized Difference Vegetation Index (NDVI):

Fig. VIII



The Normalized Difference Vegetation Index (NDVI) is the most frequently used vegetation index for greenery observation. As discussed earlier, all objects emit radiation and all objects illumined by the sun reflect radiation. Different objects absorb and reflect different portion of the Electromagnetic spectrum (EMS). For example, Chlorophyll strongly absorbs radiation in the blue and red wavelengths however reflects green wavelengths; this explains why healthy vegetation appears green. In addition, The internal structure of healthy leaves performs as excellent diffuse reflectors of Near-infrared (NIR) wavelengths, as seen in figure IX below. We can determine the health state of vegetation by monitoring and measuring the near-infrared reflectance.

Fig. IX



Healthy leaves wavelengths reflection

Green vegetation have high reflectance in NIR between 0.7 to 1.3 µm, we can see this in the spectral reflectance curves in figure VII. Thus, knowing that healthy plants have high reflectance in NIR and high absorption in Red spectrum, we can use these two bands to calculate NDVI. By using the following formula:-

NDVI = (NIR – Red) / (NIR + Red)

From the table in figure, we can assign the respective bands for each satellite.

For Landsat 7, NDVI = (Band 4 – Band 3) / (Band 4 + Band 3)

For Landsat 8, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

To monitor vegetation in drought-affected areas, it is advisable to use NIR and Short-wave infrared (SWIR). The SWIR reflectance reflects shifts in both the vegetation water content and the spongy mesophyll structure, the inner tissue of a leaf, in vegetation canopies.

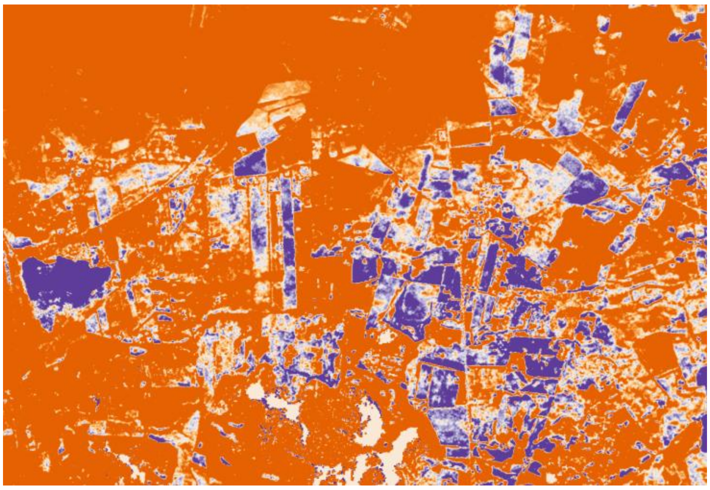
The NIR reflectance is influenced by leaf internet structures and dry matter content, however not by water content. The combination of both NIR and SWIR removes changes caused by internal leaf structure and leaf dry matter content, therefore enhancing the accuracy in recovering the vegetation water content. [3]

Ceccato, P., Flasse, S., Tarantola, S., Jacquemoud, S., & Grégoire, J. (2001). Detecting vegetation leaf water content using reflectance in the optical domain. Remote Sensing of Environment, 77(1), 22-33. doi:10.1016/s0034-4257(01)00191-2

Hence, for future reference, if we are looking for water level change such as flooding, it is desirable to use the green and NIR spectral bands.

Normalized Difference Water Index (NDWI)

Fig. X



Normalize Difference Water Index (NDWI) is used to analyze water bodies. The index uses Green and NIR bands of remote sensing images. The NDWI improves the efficiently of water information. It can be used in conjunction with NDVI to assess context of potential changes in numerous areas. Water bodies have low reflectance, as it only reflects within visible portion of the electromagnetic spectrum, we can view this in figure VII. Water bodies in their liquid state usually have high reflectance on Blue (0.4 - 0.5 µm) spectrum than Green (0.5 -0.6 µm) and Red (0.6 – 0.7 µm) spectrum.

Clearwater has higher reflectance in the blue portion of the visible spectrum. Hence, the water appears blue. There is no reflection in the NIR and beyond. NDWI is developed by McFeeters (1996) to enhance the water-related characteristics of the landscapes. NDWI uses the NIR and the SWIR bands. It can be calculated by the following formula:

One is used to observe alterations in the water content of leaves, using NIR SWIR wavelengths, proposed by Gao in 1996.

NDWI = (NIR – SWIR) / (NIR + SWIR)

Another formula is applied to observe changes related to the water level in water bodies, using green and NIR wavelengths, which was described by McFeeters (1996).

NDWI = (Green – NIR) / (Green + NIR)

For Landsat 7, NDWI = (Band 4 – Band 5) / (Band 4 + Band 5)

For Landsat 8, NDWI = (Band 5 – Band 6) / (Band 5 + Band 6)

However, the result appearing from the above formula is inferior in quality. Pure water does not reflect both NIR and SWIR. Thus, according to Xu (2005), the modified formula of NDWI by Xu (2005). It uses Green and SWIR band.

MNDWI = (Green – SWIR) / (Green + SWIR)

For Landsat 7, NDWI = (Band 2 – Band 5) / (Band 2 + Band 5)

For Landsat 8, NDWI = (Band 3 – Band 6) / (Band 3 + Band 6)

Kshetri, T. (2018, September 30). NDVI, NDBI & NDWI Calculation Using Landsat 7, 8. Retrieved from https://www.linkedin.com/pulse/ndvi-ndbi-ndwi-calculation-using-landsat-7-8-tek-bahadur-kshetri/

V. CONCLUSION

Satellite Image Processing reveal various aspects of the Earth's surface and atmosphere that are invisible to the human eye. They use novel methods and algorithms to address various problems and challenges in remote sensing domains such as urban mapping, vegetation species detection, and land/water cover change detection. Moreover, by measuring the spectral reflectance of different features on the planet, we can acquire information about their physical and chemical properties, such as temperature, moisture, vegetation, minerals, and pollution.

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