A COMPARATIVE ASSESSMENT OF REMOTE SENSING IMAGING TECHNIQUES: OPTICAL, SAR AND LIDAR

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ABSTRACT:

Remote sensing is a popular technique that is using in the mapping and monitoring of earth features. Early remote sensing was predominantly passive, i.e. it depends upon the sun for energy. Till the last decade, optical imaging is mainly used in remote sensing works. Over the time, significant innovations and improvements have been made in the active remote sensing which resulted in the form of sophisticated imaging techniques like Synthetic Aperture RADAR (SAR) and Light Detection And Ranging (LiDAR). These advancements promoted the use of multi-sensor and multi-source data in remote sensing projects. This highlights the need to review these imaging techniques. Therefore, this review work is carried out. In this review, different imaging techniques are discussed and compared. Optical, SAR and LiDAR techniques are first summarized and then they are compared on the basis of technical specification and working. Finally, an in-depth assessment is made on the applicability of these imaging techniques in different fields.

1. INTRODUCTION

For observation of the earth, remote sensing is a crucial technique through which data is gathered without coming in the physical contact of the object (Lillesand and Kiefer, 2008). Over the years lots of advancement is made in remote sensing techniques. During World War I and II several inventions are made in aerial photography (Cohen, 2000). With launch of Landsat in 1972, satellite data become readily available (Hansen and Loveland, 2012). This has increased the number of applications that rely on remote sensing.

Remote sensing works on electromagnetic radiation. Electromagnetic radiation consists of the electrical and magnetic field. Remote sensing system that measures naturally available energy is called a passive sensor. Optical imaging is the widely used passive remote sensing. Initially, it was captured through camera but later on satellite images were become popular. Most of this data is in the form of multispectral imagery with few bands. As the progress is made in sensor electronics, number of bands in multispectral image was increased. Later on, hyperspectral imaging came which consists of hundreds of narrow spectral bands. However, the problem with these images is that they depend on the external light source and weather conditions.

Subsequently, new imaging techniques like Synthetic Aperture RADAR (SAR) and Light Detection And Ranging (LiDAR) were developed. SAR uses the microwave range for remote sensing. It works on the longer wavelength range as compared to optical images. Hence, it can penetrate through cloud and vegetation cover. SAR gives the surface characteristics and moisture content. LiDAR scanning is generally performed for the generation of the three dimensional (3D) profile of the terrain. It uses near-infrared pulses for topographic applications and green light for bathymetric applications. It gives the high-resolution data as it's instruments are usually mounted on aircraft or Unmanned Air Vehicle (UAV) that can fly at low altitudes.

There are different options through which remote sensing and related studies can be performed. It is a challenge for researchers to select an appropriate technique or its combination for their work. This paper is an attempt in this direction. Although several papers are available, that performs the comparison among the imaging techniques, but most of the existing comparative studies are focused on some specific application. There is a need for a generic review and comparison of optical, SAR and LiDAR techniques. This paper bridges this research gap.

The objective of this paper is to perform a comparative analysis of imaging techniques, i.e. optical, SAR and LiDAR on the baseline of their technical specification, working and application areas. The theoretical background of the mentioned imaging techniques is first given. Then a comparison is performed on the basis of their technical specification and working. Finally, an exhaustive list of application is given, based on which comparison is performed.

2. THEORITICAL BACKGROUND

2.1 Optical Imaging

Optical remote sensing is the oldest method of remote sensing. It was started with the invention of photography. Then it is progressed as vertical and oblique air-borne photography. Later on, the remote sensing platform was moved to the space that

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resulted as space-borne remote sensing. Launch of Landsat satellite in 1972 gave a significant push in this technology. It has given the continuous data of the earth since its launch till today.

In optical imaging, electromagnetic energy of the sun which is reflected by the earth is received and measured. It's electromagnetic spectrum range is from 0.4µm to 1mm. It is a passive remote sensing technique. Hence it collects data only in daytime. The incoming energy from earth is separated into several spectral components that are sensed independently. The light wave is directed from the grating through a prism that split the energy into different wavelengths like UV, visible and near infra-red. Multispectral image is a two dimensional (2D) array of columns and rows of pixels. Each pixel contains digital number that gives spectral reflection from the object of particular band. Depending upon the number of bands it can be multispectral or hyperspectral.

As the optical remote sensing has started much earlier than the advance imaging techniques like SAR and LiDAR, therefore temporal studies are well supported by the optical images. Over the time, resolution of the images has improved. Now a day's several images have the centimeter level of accuracy. Some of the optical data are freely available like Landsat, MODIS and Sentinel but most of the high-resolution data need to be purchased at high price. There are several uses of optical data. Since the visual interpretation is much easier in the optical images, therefore, one of their primary use is in the generation of Land Use Land Cover (LULC) map. For change detection and other studies, LULC maps are widely used. It is widely used to collect data for different applications like forest mapping, earthquake and oil slick.

2.2 SAR

Microwave remote sensing can be passive as well as active. Radiometers or passive microwave sensors can measure the emitted microwave wavelengths, but they are weak in intensity. RAdio Detection And Ranging (RADAR) performs the active remote sensing which measures the physical properties of the terrain. In 1940, Side looking RADAR was developed. More sophisticated technology, SAR, was developed to improve the azimuth resolution of the RADAR systems. In 1978 first space-borne SAR, Seasat, was launched (Evans et al., 2005). RADAR was developed to detect the presence of an object and to determine their geometrical characteristics like distance and position by using radio waves. The process involves transmitting the pulses of microwave in the direction of interest and record the reflection which contains strength and position of the object. It's electromagnetic spectrum range is from 1mm to 1m.

Digital SAR image is a 2D array of columns and rows of picture element (pixel). Each pixel represents a small area of the earth surface, which gives a complex number having amplitude and phase information of the backscattered field of the microwave. Amplitude depends upon roughness and chemical composition of the object. Grey levels in the SAR image shows the properties of the object. High intensity backscattering is represented as the brighter tones while low intensity backscattering appears as the dark tone of the greyscale. Rows represent the azimuth resolution and column represents the range resolution.

Because of coherence of microwave and backscatter intensity, changes occur due to land sliding, flooding, fire etc can be detected. SAR can provide a quantitative estimation of ground changes and can be used in all weathers. With help of DInSAR (Differential SAR Interferometry) surface deformation can be calculated. It can also use to measure the velocity of slow moving landslides. PInSAR (Polarimetric SAR) is used in land cover classification and change detection. Limitation of SAR is that it gives less accuracy in dense vegetation and also affected by seasonal changes

2.3 LiDAR

LiDAR (Light Detection And Ranging) is the latest technique of active remote sensing. It has emerged in the mid-1990s. It provides data at high speed and accuracy. LiDAR transmits the pulse that ranges from ultraviolet to near-infrared range of the electromagnetic spectrum. The emitted pulse is backscatter by the earth object and received by the LiDAR instrument (Lefsky et al., 2002). The instrument measures the time delay of the pulse and thus extracts the elevation data. The elevation can be extracted because distance between transmitter and reflector can be calculated by using the travel time of laser beam as it travels at the speed of light. These reflections from the laser beam create point clouds. Thus LiDAR measures the range, orientation and intensity (Yan et al., 2015).

Two types of LiDAR are commonly used. First one is topographic LiDAR that uses the infrared laser pulses and mostly applied for the earth surface elevation mapping. Second one is bathymetric LiDAR that uses green laser pulse and applies for the water depth measurement. LiDAR scanning is mostly performed through terrestrial laser scanning or airborne laser scanning where the instruments are mounted on ground (eg vehicle) or airborne platforms (eg UAV) respectively.

LiDAR generates a very high resolution and good quality DEM that can be used in several applications like flood hazard zoning, forest mapping, bathymetry, coastal erosion monitoring, glacier studies etc (Jahncke et al., 2018; Joyce et al., 2014; Lennon et al., 2005). LiDAR data have limited spatial coverage. LiDAR data is scattered over the scanned area in the form of point cloud. Thus, it does not provide continuous coverage of that area.

3. COMPARISON OF IMAGING TECHNIQUES

3.1 On the Basis of Technical Specification and Working

Comparison between optical, SAR and LiDAR imaging techniques is carried out through the review of research papers along with the books like Lillesand and Kiefer (2008) and Jensen (2014). It is based on seventeen different technical and working parameters. Table 1 summarizes this comparison.

3.2 On the Basis of Application

Another comparative assessment of optical, SAR and LiDAR imaging techniques is performed on the basis of their application in different fields. Recent remote sensing studies involve the use of multi-source data. Therefore, in several applications these techniques are used jointly. Each of them enriches the output in their unique way. Table 2 summarizes this comparison.

Characteristics/ Properties	**Optical**	**SAR**	**LiDAR**
Electromagnetic range	0.4µm to 1mm	1mm to 1m	250 nm to 10 µm Mostly monochromatic wavelength is used. Recently some systems like Optech Titan started the use of multiband data
Sensor direction for the receiving of electromagnetic radiation	Near vertical	Oblique	Near vertical
Information in pixel	Spectral reflection of the particular band.	Amplitude and phase	Not applicable because 3D point cloud is formed that contains the planimetric, altitude and intensity data.
Range Resolution (Weijie and Xiaojie, 2016)	Ground range is used.	Slant range is used.	3D point cloud is formed.
Dielectric constant	Independent	Highly dependent	Independent
Coverage Area	Large	Large	Small
Type of errors (Devapal et al., 2019)	Skew distortion, panoramic distortion, haze, error due to varying solar illumination conditions and error due to unstable platform.	Speckle, layover and foreshortening.	Error due to unstable platform, multipath error, calibration errors of GPS and inertial measurement unit.
Classification error due to self and cast shadow (Lin et al., 2019)	It is affected by the shadow that leads to the misclassification of pixel into low reflectance objects like water.	It is affected from the shadow that leads to the misclassification.	Its integration with other data helps to identify the shadow that improves the classification.
Weather dependence (Liu et al., 2019)	Cannot penetrate through clouds; therefore, image is acquired only in clear weather.	Microwaves can penetrate through clouds; therefore, image is acquired in any weather.	Scanning should be performed in cloud free condition.
Cost	Free to expensive. Prize varies according to images resolution. Most of the high resolution images are not free of cost.	Free to expensive Prize varies according to images resolution	High cost Very small amount of data is freely available.
Survey Customization	Only aerial photography can be customized.	Not possible	Airborne and terrestrial scanning can be customized.
Terrain mapping continuity	Provides a continuous mapping of terrain.	Provides a continuous mapping of terrain.	Does not provide a continuous mapping of terrain. Sampling is done at a certain interval through laser pulses.
Displacement detection	Horizontal	Horizontal and vertical	Horizontal and vertical
Bathymetry	Visible and IR waves cannot transmit through water	Microwaves can transmit through water.	Green light is used that can transmit through water.
DEM (Joyce et al., 2009; Polat et al., 2015)	It can be generated by using photogrammety on stereo pair. Terrain slope effects the DEM generation.	The interferogram is generated by using two complex SAR images and then by using phase unwrapping technique DEM is generated.	Raw data contains the elevation information. Filtering is applied on it to remove the non-ground points. Interpolation is then applied to generate the DEM.
Parallax measurement	Parallax measurement accuracy is usually from centimeters to meters, in the order of the resolution of the imagery.	The accuracy of InSAR parallax measurement is typically ranges from several millimeters to centimeters, in the fraction of SAR wavelength	Not applicable.
Maturity	High. Instruments and algorithms are available and well tested	Medium	Low, it is still in the conception stage.

Table 1. Comparison between optical, SAR and LiDAR imaging techniques on the basis of technical specification and working

Application	Optical	SAR	LiDAR
Vegetation (Li and Guo, 2016)	It gives the biophysical and biochemical data through the study of leaf pigmentation and structure is performed.	It can give the information about the moisture content and structure of the canopy.	It can give the horizontal and vertical structure of the canopy.
Within vegetation canopy (Montgomery et al., 2019)	Cannot penetrate through vegetation.	It can penetrate the vegetation canopy and can study the surface water or flood extent.	It can penetrate the vegetation canopy and can measure its structure or terrain features.
Agriculture (Kumar and Agrawal, 2019; Sofonia et al., 2019; Zhang et al., 2019)	Pest infection and disease can be identified as it appears in the form of change in spectral reflectance. Change in photosynthetic processes can be determined through the near-infrared band. Crop growth monitoring and yield estimation can be performed. Abandoned agricultural land can be identified.	It detects water content of the plant and the soil characteristics which can support the crop disease detection. Helps in crop growth monitoring.	It creates 3D canopy that can help to assess the damages caused by any disease. It can estimate the top canopy and ground elevation that helps in the crop growth approximation.
Wetland mapping (Jahncke et al., 2018)	Suitable for the mapping of vegetation condition and vegetation indices like NDVI.	Due to the high dielectric constant, water acts as a specular reflector. Therefore it appears dark in image. Suitable for the mapping of water, moisture and water level along with the surface texture.	Precise DEM generated by it helps in the wetland classification along with the calculation of parameters like slope, curvature, topographic position index and flow accumulation.
River mapping (Obida et al., 2019)	River network delineation can be done through classification and water indices calculation.	Raster based river network can be delineation by which corresponding vector data is generated through the thinning.	DEM generated by it can be used to calculate the slope, flow direction, water accumulation and catchment characteristics.
Glacier mapping (Kaushik et al., 2019)	Glacier delineation can be performed by using manual digitization, band ratio or classification. It can help in the estimation of flow velocity and mass change.	Supra glacial and peri glacial debris can be differentiated through coherence pattern analysis. Active and stagnant ice can be differentiated.	DEM generated by it is used in the calculation of topographic and morphometric parameters. It can be used in snow depth measurement.
Urbanization (Iino et al., 2018; Varol et al., 2019)	High-resolution images help in urban planning, monitoring and cadastral mapping. It can be used in the validation of results produced by other techniques.	SAR and polarimetric SAR are used in the LULC mapping and in the study of the highly dense and complex built-up area.	DSM generated by it utilized in 3D city modelling and change detection. It provides precise detection of buildings that are higher than the prescribed limit.
Analysis of deformations events like landslide, earthquake, land subsidence etc (Tiwari et al., 2018)	It assesses infrastructure damages and ground changes.	Identifies one dimensional movement of the surface in the satellite line of sight direction through differential interferograms of pre and post event.	DEM generated by it measures the upper and lower scarp that helps in the measurement of vertical displacement, which specifies subsidence.
Archaeological ruin and paleo landscape detection (Luo et al., 2019)	If the buried structures make changes in the chemical, physical or biological characteristics of the soil then they can be detected in the form of soil discoloration or change in vegetation phenology. Very narrow spectral bands can identify even subtle spectral reflectance differences.	Better in buried feature detection. Backscattered signal provides the surface characteristics that help in archaeological objects detection. Higher frequency bands have greater penetration power of surface and vegetation that gives the information of buried ruins.	Bathymetric LiDAR is used in sea floor mapping and submerged structure detection Highly precise LiDAR DEM and DSM help to identify and interpret the archaeological sites.

Application	Optical	SAR	LiDAR
Oil spill detection in water (Raimondi et al., 2017; Sun et al., 2018)	Sun glint makes the oil contrast high as compared to water in the image Crude oil has high absorption in the blue band that helps to distinguish it. Emulsified oil with water has high scattering in the red, near-infrared and shortwave infrared band that helps to detect it.	Oil increases the viscosity that makes the sea surface to appear smoother. Due to this low backscattering occurs, which makes oil spilled area appearance darker in SAR image. This helps to discriminate it from the water.	Fluorescence LIDAR can detect the oil spills and can measure its thickness
Temperature studies (Dutta et al., 2018; He et al., 2019)	Thermal band of the images is used to calculate the land surface temperature that can help in temperature related studies like urban heat island detection etc.	Cannot be used directly for temperature measurement. DEM generated by it can help in the analysis of temperature anomaly generated due to terrain shading or shadowing.	Atmospheric LiDAR can measure the temperature. Like rotational Raman LiDAR measures the temperature in troposphere and stratosphere. DEM generated by it can help in the analysis of temperature anomaly generated due to terrain shading or shadowing.

Table 2. Comparison between optical, SAR and LiDAR imaging techniques on the basis of applications

4. CONCLUSION

Remote sensing is continuously developing and several imaging options have emerged over time. Selection of the suitable imaging technique is a challenge where the final decision is influenced by the available expertise, data and budget. This paper is an attempt to provide support in the selection of imaging technique. Therefore, a comparative study of heterogeneous imaging techniques is performed in this paper. It is found that each imaging technique has its advantage. Optical images can provide information about actual features which are present on the earth surface. SAR data provides surface characteristics. LiDAR data provides excellent quality of DEM. These techniques are complementary to each other. For example integration of SAR data with optical and LiDAR data can accelerate the development of multisensory analysis. LiDAR has shown the potential to be used in the more accurate orthorectification of optical and SAR data. Thus as a concluding remark, it stated that the synergetic application of optical, SAR and LiDAR could create endless opportunities in the field of remote sensing which cannot be performed by using any of the imaging technique in a standalone manner.

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