Intercontinental Geoinformation Days

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Applications of Remote Sensing in Solving Myriads of Geological Problems: A Review

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Keywords
Remote sensing
Geological terrains
Electromagnetic spectrum
Geological mapping
Ground-truthing

ABSTRACT

Numerous geological problems can be conveniently solved through the application of remote sensing techniques. This work seeks to review the available literature on remote sensing utilization in geological and geotechnical sciences. It however observed that remote sensing makes possible the collection of data from dangerous or inaccessible geological terrains and is applicable in geological mapping, landform studies/characterization, mineral/rock identification, soil properties (such as soil texture, moisture content of the soil, soil organic carbon, and soil salinity), geodetic survey, geomorphological studies, and detection of geologic hazards. Other uses of remote sensing include oil spill detection and monitoring and by integrating with Geographical Information System (GIS), it is a perfect match for hydrological studies, landslide, and urban planning. Though remote sensing in geology has limitations such as limited capabilities, data volume for transmission and inconsistency in data acquisition and interpretation, ground-truthing surveys and repeated reconnaissance remain the irreplaceable solutions to these limitations.

1. Introduction

Remote sensing is used in the geological sciences as a data acquisition method complementary to field observation because it allows the mapping of geological terrains without physical contact with the areas being explored (Rees, 2013). About one-fourth of the earth's total surface area is exposed land where information can be extracted through observation of the earth via remote sensing (Kuehn et al., 2000).

Remote sensing is made possible by the detection of electromagnetic radiation by sensors. The radiation can be naturally sourced as applicable to passive remote sensing or produced by machines as applicable to active remote sensing and reflected off the earth's surface (Rees, 2013). The information carrier being electromagnetic radiation has two main variables: intensities of reflectance and travel-time of radiation.

The detection of intensities of reflectance at different wavelengths is plotted on a spectral reflectance curve. This spectral characteristic is aided by the physio-chemical properties of the surface of the target object and therefore are very vital in mineral identification and geological mapping, for example, hyper-spectral imaging (Rees, 2013). Additionally, the two-way travel time of radiation from and back to the sensor can be used to calculate the distance in active remote sensing systems, for example, interferometric synthetic-aperture radar. This is employed in geomorphological studies of ground motion and has the ability of illuminating deformations connected with earthquakes, landslides, volcanism, etc. (Gupta, 1991).

Geological studies with the aid of remote sensing commonly employ a multitude of tools classified according to short to long wavelengths of the electromagnetic radiation which various instruments are sensitive to. Shorter wavelengths are generally useful for site characterization up to mineralogical scale, while longer wavelengths reveal larger-scale surface information, such as regional thermal anomalies, surface roughness, etc (Gupta, 1991). Such techniques are particularly beneficial for the exploration of inaccessible areas, and planets other than Earth.

Remote sensing data can also help in the studies involving mapping of geological hazards and economic geology, that is, exploration for minerals, petroleum, etc. Soils and vegetation that preferentially grow above different types of rocks can be used to deduce the underlying geological patterns through remote sensing in geology.

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Cite this study

Aguta O O, Oladotun M O & Jephthah S O (2021). Applications of Remote Sensing in Solving Myriads of Geological Problems: A Review. 3rd Intercontinental Geoinformation Days (IGD), 160-163, Mersin, Turkey

Remote sensing data is often visualized using Geographical Information System (GIS) tools (Gupta, 1991; Ray and Lazzari, 2020).

2. Techniques of remote sensing

Remote sensing techniques consist of a sensor which could be spaceborne (carried by satellite), airborne (carried by aircraft, or most recently, Unmanned Aerial Vehicle (UAV)) or ground-based (sometimes called proximal sensing) (Colomina and Molina, 2014) and is carried by a platform and which operates on the environment to produce data.

The data acquired from higher elevation capture a larger spatial coverage, but the resolutions are often low (Bürgmann and Thatcher, 2013) and are then transformed into information by several operations collectively called reduction and analysis. Such information gathered from the data will eventually be applied for different purposes (geology, mineral exploration, soils, forestry, military, disaster control, etc.) depending on the user's requirements.ed.

2.1. Sensors

The sensors used in remote sensing are varied in type and classification. For instance, sensors can be either active or passive. Active sensors produce their own energy in order to be able to gather data such as film photography, infrared, charge-coupled devices, and radiometers, while passive sensors depend on and utilize energy from external sources. Examples of passive sensors are Radio Detection and Ranging (RADAR) and Light Detection and Ranging (LIDAR).

Another classification is either imaging or non-imaging. Imaging sensors reproduce data in image format (like aerial photographic cameras, multi-spectral scanners, and side-looking radar (SLR)) whereas non-imaging sensors produce data which cannot be transformed into images (e.g. s194, an L-band radiometer system used in Skylab/EREP experiments). Sensor classification could also be according to the spectral region/bands within which they operate. Examples include visible light, infrared and microwave. All the mentioned classes of sensors are useful in geologic applications (Wikipedia.org).

2.2. Platforms

The platforms employed in carrying sensors for remote sensing are of different types. The most commonly used are aircraft, spacecraft, and Unmanned Aerial vehicles (UAV).

2.3. Environment

In natural resource surveys, the environment is usually part of the earth's surface. For geological purposes, however, this will naturally be restricted to the land-covered areas of the earth. Other examples of environment include extra-terrestrial bodies such as the moon, Mars, Jupiter, and other celestial bodies which in recent years have also been objects of remote sensing activities (Wikipedia.org).

2.4. Data

The data produced by the sensors can either be of the photographic type such as in the case with camera systems or of the digital type which is originally stored in magnetic tape, such as multi-spectral scanning systems (MSS) (FAO, 2020).

2.5. Information

We seek to derive information from data produced by the sensor. Afterward, operations called "data reduction and analysis" are carried out. This can be done purely visually as is done in conventional photo-interpretation or partly with the aid of machines/computers. Visual analysis is referred to as image orientation while digital (computer) analysis is called numerical orientation. Geologists seek to derive geological information usually stored on a format (such as thematic map) and may be accompanied by graphs, tabulations, and a report. The goal of these information depends on the users' interest. The trend of improvement of remote sensing emanates from panchromatic, multi-spectral, hyper-spectral to ultra-spectral which has greatly affected the quality of the information because of the rise in spectral resolution (Roy and Vandana, 2009).

2.6. Application

The final step in remote sensing is the application of the data. Applications depend on the users' interests. For instance, if a geological map is the final product of the analysis, the information contained in the map may find different applications in hydrogeology, engineering geology, mineral exploration, geological survey, or it may serve as a scientific document (Hakim et al., 2018 and Wikipedia. org).

3. Electromagnetic spectrum: the working principle of remote sensing

In remote sensing, two main variables are measured in a typical remote sensing system: the radiance (or intensity) and time of arrival for active systems (Rees, 2013). As a point to note, the data collected is a blend of both reflections of solar radiation and emission (according to Planck's law) from the object of visible and near-infrared (VNIR) region (Vincent, 1997). The thermal infrared (TIR) region measures mainly emission while the microwave region records the backscattering portion of reflection. The radiance is determined by radiation-matter interactions, which are governed by the physio-chemical properties of the target object (Vincent, 1997).

However, since the sensors are looking through the atmosphere to reach the target, there is atmospheric absorption and three main atmospheric windows, which allow penetration of radiation are involved and are therefore, the most useful range of the spectrum. They are 0.4–3 micro-meters (Visible and near-infrared (VNIR)), 3–14 micro-meters (Thermal Infrared TIR), and few millimeters to meters (microwave) (Rees, 2013; Vincent, 1997).

4. Applications of remote sensing in geology

Remote sensing finds various applications in geological sciences. They include:

4.1. Geological mapping

Remote sensing aids surficial geological mapping and landform characterization. Rock-bearing minerals are identified via aerial photographs using a logical method, which indicates those things the rocks contain that enable them to be seen in an aerial photograph. These logical methods are texture, colour, and tone of the photograph, drainage pattern, vegetation cover, and cultivation. Apart from mineral/rock identification, soil properties (such as soil texture, moisture content of the soil, soil organic carbon, and soil salinity), geodetic survey, geomorphological features, geologic hazards (such as tsunami, earthquakes, and volcanism), and mapping of inaccessible areas are made possible by remote sensing. The end product of remote sensing application in geological mapping is thematic map (Robert, 2007).

4.2. Petroleum exploration

The short wavelength region of visible and near-infrared (VNIR) can be used to estimate the petroleum reservoir because it provides both accurate distance measurements by LiDAR and spectral data from spectral scanning (Hodgetts, 2013). The study by Lord in 2017 at Pennsylvania, USA indicates that remote sensing application provided insights into seepage emanating from leaking abandoned wells in addition to the naturally occurring seepage.

4.3. Groundwater investigations

Remote sensed data can infer possible confined/ unconfined aquifers (Jha et al., 2007). For instance, in radar data (ground penetrating radar), which can penetrate deep meters into the ground, will indicate some diffuse reflection for a rough surface in relation to the wavelength used. The change in lithology may suggest soft rock and unconsolidated sediments with high porosity indicates groundwater accumulation (Wikipedia.org).

4.4. Planetary observation

Planetary explorations are made simpler without sending an astronaut into space by remote sensing. For most planetary explorations, due to the thick atmosphere, radar is suitable instrumentation to investigate planetary surfaces as it can penetrate the atmosphere and detect surface roughness. Also, from the mapping of Venus, it is seen that topographic maps could be obtained from radar altimetry and InSAR methods (Wikipedia.org).

4.5 Image processing

Image processing is crucial to converting raw data into useful information. For imaging remote sensing, where spectral data are collected and recorded in pixels of an image, a two-dimensional representation. After removal of noise and calibration, images are then geo-referenced to relate pixel to real-life geography. The first-hand data are then corrected to remove noise such as atmospheric disturbance, structural effects, and distortion. The image interpretation could be achieved by an interpreter or computation (Gupta, 1991).

5. Integration of remote sensing with geographical information system (GIS)

The techniques of remote sensing are closely connected to advance data interpretation and visualization, which is among the capabilities in Geographical Information System (GIS) (Jensen, 2007; Rees, 2013; Kuehn et al., 2000)). The GIS also allows the input of other information such as socioeconomic conditions and biophysical conditions in terms of layers (Jha et al., 2007). Further, analyses in the same spatial extent are carried out and thematic maps are then generated for presentation (Jensen, 2007; Rees, 2013).

6. The limitations of remote sensing application in geology

There is no ideal sensor capable or optimized to study everything in geology. Therefore, it is of geologist's preference and skill to choose which dataset and excerpt information therein (Gupta, 1991). For instance, in cloud-free areas, aerial photography is more sensible, but radar performs better for overcast weather. Resolution (spatial and spectral) and lack of stereoscopy in many geological investigations are also limiting factors of remote sensing application in geology (Bhan and Krishnanunni, 1983). There is a trade-off between spatial resolution and spectral resolution (Vincent, 1997).

Stratigraphic and lithologic discrimination which make rock types to appear with little or no spectral differences is also a limiting factor in geological mapping from space (Bhan and Krishnanunni, 1983).

Another limitation is the inconsistent data acquisition method, and their interpretation patterns/processes (Mulder *et al.*, 2011).

6.1. The solutions to the limitations

Many authors like Bhan and Krishnanunni in 1983, Gupta in 1991, Colomina and Molina in 2014 and Mulder et al in 2011 considers the following as solutions to the above inherent challenges of applying remote sensing in geology.

6.1.1. Ground-truthing

Even with the present state of the art in remote sensing, it cannot totally replace conventional methods of field mapping because such ground-truthing makes remote-sensing data meaningful. Otherwise, roads will be interpreted as ore-bearing fractures while rounded building roofs will be interpreted as salt domes. Thus, remote sensing data are usually validated by ground-truthing surveys, which serves as training data in image classification to ensure quality (Gupta, 1991, Mulder *et al*., 2011).

6.1.2. Repeated reconnaissance

Repeated reconnaissance is recommended for studying a specific geologic terrain (Colomina and Molina, 2014). Field observation and reconnaissance remain irreplaceable and shall never be taken over completely by remote sensing because field data greatly support remote sensing data interpretation. Remote sensing should be viewed as complementary to field survey aimed at providing instantaneous views of different scales, perspectives or spectral vision (Gupta, 1991).

6.1.3. Advances in sensor development

Bhan and Krishnanunni in 1983 opines that invention of sensors with finer spatial resolution and more spectral bands particularly in the region of middle and thermal infra-red with sharper spectral separation, and also, improvement in geometric fidelity and greater radiometric accuracy along with stereoscopy are the solutions to the remote sensing limitation on resolution and stereoscopy. More so, digital enhancement of MSS data using computer techniques made stratigraphic and lithologic discrimination possible (Bhan and Krishnanunni, 1983).

7. Conclusion

Remote sensing is an emerging technology with usefulness in solving many geological problems that cannot be exhaustive as it has the ability to explore and collect data from dangerous and inaccessible geological terrains with a limited view of the human eye. It also reduces the burden of fieldwork required for mapping of areas through synoptic studies. Hence, remote sensing helps in landform or geomorphological studies, groundwater and petroleum exploration, rock and mineral identification, geodetic survey, and detection of geologic hazards. In this paper, the remote sensing techniques, working principles, various application in geological sciences, its limitations and possible solutions were discussed, which could be a basic reference for future studies on the application of remote sensing in geological sciences.

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