Geographical Information Systems (GIS)

Introduction

Geographical Information System (GIS) is a technology that provides the means to collect and use geographic data to assist in the development of Agriculture. A digital map is generally of much greater value than the same map printed on a paper as the digital version can be combined with other sources of data for analyzing information with a graphical presentation. The GIS software makes it possible to synthesize large amounts of different data, combining different layers of information to manage and retrieve the data in a more useful manner. GIS provides a powerful means for agricultural scientists to better service to the farmers and farming community in answering their query and helping in a better decision making to implement planning activities for the development of agriculture.

Overview of GIS

A Geographical Information System (GIS) is a system for capturing, storing, analyzing and managing data and associated attributes, which are spatially referenced to the Earth. The geographical information system is also called as a geographic information system or geospatial information system. It is an information system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information. In a more generic sense, GIS is a software tool that allows users to create interactive queries, analyze the spatial information, edit data, maps, and present the results of all these operations. GIS technology is becoming essential tool to combine various maps and remote sensing information to generate various models, which are used in real time environment. Geographical information system is the science utilizing the geographic concepts, applications and systems.

Geographical Information System can be used for scientific investigations, resource management, asset management, environmental impact assessment, urban planning, cartography, criminology, history, sales, marketing, and logistics. For example, agricultural planners might use geographical data to decide on the best locations for a location specific crop planning, by combining data on soils, topography, and rainfall to determine the size and location of biologically suitable areas. The final output could include overlays with land ownership, transport, infrastructure, labour availability, and distance to market centers.

History of GIS development

The idea of portraying different layers of data on a series of base maps, and relating things geographically, has been around much older than computers invention. Thousands years ago, the early man used to draw pictures of the animals they hunted on the walls of caves. These animal drawings are track lines and tallies thought to depict migration routes. While simplistic in comparison to modern technologies, these early records mimic the two-element structure of modern geographic information systems, an image associated with attribute information.

Possibly the earliest use of the geographic method, in 1854 John Snow depicted a cholera outbreak in London using points to represent the locations of some individual cases. His study of the distribution of cholera led to the source of the disease, a contaminated water pump within the heart of the cholera outbreak. While the basic elements of topology and theme existed previously in cartography, the John Snow map was unique, using cartographic methods, not only to depict but also to analyze, clusters of geographically dependent phenomena for the first time.

The early 20th century saw the development of "photo lithography" where maps were separated into layers. Computer hardware development spurred by nuclear weapon research led to general-purpose computer "mapping" applications by the early 1960s. In the year 1962, the world's first true operational GIS was developed by the federal Department of Forestry and Rural Development in Ottawa, Canada by Dr. Roger Tomlinson. It was called the "Canada Geographic Information System" (CGIS) and was used to store, analyze, and manipulate data collected for the Canada Land Inventory (CLI). It is an initiative to determine the land capability for rural Canada by mapping information about soils, agriculture, recreation, wildlife, forestry, and land use at a scale of 1:50,000.

CGIS was the world's first "system" and was an improvement over "mapping" applications as it provided capabilities for overlay, measurement, and digitizing or scanning. It supported a national coordinate system that spanned the continent, coded lines as "arcs" having a true embedded topology, and it stored the attribute and location specific information in a separate files. Dr. Tomlinson is known as the "father of GIS," for his use of overlays in promoting the spatial analysis of convergent geographic data.

In 1964, Howard T Fisher formed the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Graduate School of Design, where a number of important theoretical concepts in spatial data handling were developed. This lab had major influence on the development of GIS until early 1980s. Many pioneers of newer GIS "grew up" at the Harvard lab and had distributed seminal software code and systems, such as 'SYMAP', 'GRID', and 'ODYSSEY'.

By the early 1980s, M&S Computing (later Intergraph), Environmental Systems Research Institute (ESRI) and CARIS emerged as commercial vendors of GIS software, successfully incorporating many of the CGIS features, combining the first generation approach to separation of spatial and attribute information with a second generation approach to organizing attribute data into database structures. More functions for user interaction were developed mainly in a graphical way by a user friendly interface (Graphical User Interface), which gave to the user the ability to sort, select, extract, reclassify, reproject and display data on the basis of complex geographical, topological and statistical criteria. During the same time, the development of a public domain GIS begun by the U.S. Army Corp of Engineering Research Laboratory (USA-CERL) in Champaign, Illinois, a branch of the U.S. Army Corps of Engineers to meet the need of the United States military for software for land management and environmental planning.

In the years 1980s and 1990s industry growth were spurred on by the growing use of GIS on Unix workstations and the personal computers. By the end of the 20th century, the rapid growth in various systems had been consolidated and standardized on relatively few platforms and users were beginning to export the concept of viewing GIS data over the Internet, requiring uniform data format and transfer standards. More recently, there is a growing number of free, open source GIS packages, which run on a range of operating systems and can be customized to perform specific tasks. As computing power increased and hardware prices slashed down, the GIS became a viable technology for state development planning. It has become a real Management Information System (MIS), and thus able to support decision making processes.

Components of GIS

GIS enables the user to input, manage, manipulate, analyze, and display geographically referenced data using a computerized system. To perform various operations with GIS, the components of GIS such as software, hardware, data, people and methods are essential.

Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are (a) a database management system (DBMS) (b) tools for the input and manipulation of geographic information (c) tools that support geographic query, analysis, and visualization (d) a graphical user interface (GUI) for easy access to tools. GIS software are either commercial software or software developed on Open Source domain, which are available for free. However, the commercial software is copyright protected, can be expensive and is available in terms number of licensees.

Currently available commercial GIS software includes Arc/Info, Intergraph, MapInfo, Gram++ etc. Out of these Arc/Info is the most popular software package. And, the open source software are AMS/MARS etc.

Hardware

Hardware is the computer on which a GIS operates. Today, GIS runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations. Minimum configuration required to Arc/Info Desktop 9.0 GIS application is as follows:

Product: ArcInfo Desktop 9.0

Platform: PC-Intel

Operating System: Windows XP Professional Edition, Home Edition

Service Packs/Patches: SP 1

SP2 (refer to Limitations)

Shipping/Release Date: May 10, 2004

Hardware Requirements

CPU Speed: 800 MHz minimum, 1.0 GHz recommended or higher

Processor: Pentium or higher

Memory/RAM: 256 MB minumum, 512 MB recommended or higher

Display Properties: Greater than 256 color depth

Swap Space: 300 MB minimum

Disk Space: Typical 605 MB NTFS, Complete 695 MB FAT32 + 50 MB for installation

Browser: Internet Explorer 6.0 Requirement:

(Some features of ArcInfo Desktop 9.0 require a minimum installation of Microsoft Internet Explorer Version 6.0.)

Data

The most important component of a GIS is the data. Geographic data or Spatial data and related tabular data can be collected in-house or bought from a commercial data provider. Spatial data can be in the form of a map/remotely-sensed data such as satellite imagery and aerial photography. These data forms must be properly geo-referenced (latitude/longitude). Tabular data can be in the form attribute data that is in some way related to spatial data. Most GIS software comes with inbuilt Database Management Systems (DBMS) to create and maintain a database to help organize and manage data.

Users

GIS technology is of limited value without the users who manage the system and to develop plans for applying it. GIS users range from technical specialists who design and maintain the system to those who use it to help them do their everyday work.

These users are largely interested in the results of the analyses and may have no interest or knowledge of the methods of analysis. The user-friendly interface of the GIS software allows the nontechnical users to have easy access to GIS analytical capabilities without needing to know detailed software commands. A simple User Interface (UI) can consist of menus and pull-down graphic windows so that the user can perform required analysis with a few key presses without needing to learn specific commands in detail.

Methods

A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization.

Functions of GIS

General-purpose GIS software performs six major tasks such as input, manipulation, management, query and analysis, Visualization.

Input

The important input data for any GIS is digitized maps, images, spatial data and tabular data. The tabular data is generally typed on a computer using relational database management system software. Before geographic data can be used in a GIS it must be converted into a suitable digital format. The DBMS system can generate various objects such as index generation on data items, to speed up the information retrieval by a query.   Maps can be digitized using a vector format in which the actual map points, lines, and polygons are stored as coordinates. Data can also be input in a raster format in which data elements are stored as cells in a grid structure (the technology details are covered in following section).

The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology has the capability to automate this process fully for large projects; smaller jobs may require some manual digitizing. The digitizing process is labour intensive and time-consuming, so it is better to use the data that already exist.

Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from data suppliers and loaded directly into a GIS.

Manipulation

GIS can store, maintain, distribute and update spatial data associated text data. The spatial data must be referenced to a geographic coordinate systems (latitude/longitude). The tabular data associated with spatial data can be manipulated with help of data base management software. It is likely that data types required for a particular GIS project will need to be transformed or manipulated in some way to make them compatible with the system. For example, geographic information is available at different scales (scale of 1:100,000; 1:10,000; and 1:50,000). Before these can be overlaid and integrated they must be transformed to the same scale. This could be a temporary transformation for display purposes or a permanent one required for analysis. And, there are many other types of data manipulation that are routinely performed in GIS. These include projection changes, data aggregation, generalization and weeding out unnecessary data.

Management

For small GIS projects it may be sufficient to store geographic information as computer files. However, when data volumes become large and the number of users of the data becomes more than a few, it is advised to use a database management system (DBMS) to help store, organize, and manage data. A DBMS is a database management software package to manage the integrated collection of database objects such as tables, indexes, query, and other procedures in a database.

There are many different models of DBMS, but for GIS use, the relational model database management systems will be highly helpful. In the relational model, data are stored conceptually as a collection of tables and each table will have the data attributes related to a common entity. Common fields in different tables are used to link them together with relations. Because of its simple architecture, the relational DBMS software has been used so widely. These are flexible in nature and have been very wide deployed in applications both within and without GIS.

Query

The stored information either spatial data or associated tabular data can be retrieved with the help of Structured Query Language (SQL). Depending on the type of user interface, data can be queried using the SQL or a menu driven system can be used to retrieve map data. For example, you can begin to ask questions such as:

- Where are all the soils are suitable for sunflower crop?
- What is the dominant soil type for Paddy?
- What is the groundwater available position in a village/block/district?

Both simple and sophisticated queries utilizing more than one data layer can provide timely information to officers, analysts to have overall knowledge about situation and can take a more informed decision.

Analysis

GIS systems really come into their own when they are used to analyze geographic data. The processes of geographic analysis often called spatial analysis or geo-processing uses the geographic properties of features to look for patterns and trends, and to undertake "what if" scenarios. Modern GIS have many powerful analytical tools to analyse the data. The following are some of the analysis which are generally performed on geographic data.

A. Overlay Analysis

The integration of different data layers involves a process called overlay. At its simplest, this could be a visual operation, but analytical operations require one or more data layers to be joined physically. This overlay, or spatial join, can integrate data on soils, slope, and vegetation, or land ownership. For example, data layers for soil and land use can be combined resulting in a new map which contains both soil and land use information. This will be helpful to understand the different behaviour of the situation on different parameters.

B. Proximity Analysis

GIS software can also support buffer generation that involves the creation of new polygons from points, lines, and polygon features stored in the database. For example, to know answer to questions like; How much area covered within 1 km of water canal? What is area covered under different crops? And, for watershed projects, where is the boundary or delineation of watershed, slope, water channels, different types water harvesting structures are required, etc.

Visualization

GIS can provide hardcopy maps, statistical summaries, modeling solutions and graphical display of maps for both spatial and tabular data. For many types of geographic operation the end result is best visualized as a map or graph. Maps are very efficient at storing and communicating geographic information. GIS provides new and exciting tools to extend the art of visualization of output information to the users.

Technology used in GIS

Data creation

Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a computer-aided design program with geo-referencing capabilities. With the wide availability of rectified imagery (both from satellite and aerial sources), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of through the traditional method of tracing the geographic form on a separate digitizing tablet.

Relating information from different sources

If you could relate information about the rainfall of a state to aerial photographs of county, you might be able to tell which wetlands dry up at certain times of the year. A

GIS, which can use information from many different sources in many different forms, can help with such analyses. The primary requirement for the source data consists of knowing the locations for the variables. Location may be annotated by x, y, and z coordinates of longitude, latitude, and elevation, or by other geocode systems like postal codes. Any variable that can be located spatially can be fed into a GIS. Different kinds of data in map form can be entered into a GIS.

A GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. For example, digital satellite images generated through remote sensing can be analyzed to produce a map-like layer of digital information about vegetative covers. Likewise, census or hydrologic tabular data can be converted to map-like form, serving as layers of thematic information in a GIS.

Data representation

GIS data represents real world objects such as roads, land use, elevation with digital data. Real world objects can be divided into two abstractions: discrete objects (a house) and continuous fields (rain fall amount or elevation). There are two broad methods used to store data in a GIS for both abstractions: Raster and Vector.

Raster

A raster data type is, in essence, any type of digital image. Anyone who is familiar with digital photography will recognize the pixel as the smallest individual unit of an image. A combination of these pixels will create an image, distinct from the commonly used scalable vector graphics, which are the basis of the vector model. While a digital image is concerned with the output as representation of reality, in a photograph or art transferred to computer, the raster data type will reflect an abstraction of reality. Aerial photos are one commonly used form of raster data, with only one purpose, to display a detailed image on a map or for the purposes of digitization. Other raster data sets will contain information regarding elevation, a DEM (digital Elevation Model), or reflectance of a particular wavelength of light.

Digital elevation model, map, and vector data, Raster data type consists of rows and columns of cells each storing a single value. Raster data can be images (raster images) with each pixel containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, colormaps (a mapping between a thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units.

Raster data is stored in various formats; from a standard file-based structure of TIF, JPEG formats to binary large object (BLOB) data stored directly in a relational database management system (RDBMS) similar to other vector-based feature classes. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly sized records.

Vector

A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake. In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. In the popular ESRI Arc series of programs, these are explicitly called shape files. Different geographical features are best expressed by different types of geometry:

Points

Zero-dimensional points are used for geographical features that can best be expressed by a single grid reference; in other words, simple location. For example, the locations of wells, peak elevations, features of interest or trailheads. Points convey the least amount of information of these file types.

Lines or polylines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines.

Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types.

Each of these geometries are linked to a row in a database that describes their attributes. For example, a database that describes lakes may contain a lake's depth, water quality, pollution level. This information can be used to make a map to describe a particular attribute of the dataset. For example, lakes could be coloured depending on level of pollution. Different geometries can also be compared. For example, the GIS could be used to identify all wells (point geometry) that are within 1-mile (1.6 km) of a lake (polygon geometry) that has a high level of pollution.

Vector features can be made to respect spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines and triangulated irregular networks (TIN) are used to represent elevation or other continuously changing values. TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles. The face of the triangles represent the terrain surface.

Advantages and disadvantages

There are advantages and disadvantages to using a raster or vector data model to represent reality. Raster data sets record a value for all points in the area covered which may require more storage space than representing data in a vector format that can store data only where needed. Raster data also allows easy implementation of overlay operations, which are more difficult with vector data. Vector data can be displayed as vector graphics used on traditional maps, whereas raster data will appear as an image that may have a blocky appearance for object boundaries. Vector data can be easier to register, scale, and re-project. This can simplify combining vector layers from different sources. Vector data are more compatible with relational database environment. They can be part of a relational table as a normal column and processes using a multitude of operators.

The file size for vector data is usually much smaller for storage and sharing than raster data. Image or raster data can be 10 to 100 times larger than vector data depending on the resolution. Another advantage of vector data is it can be easily updated and maintained. For example, a new highway is added. The raster image will have to be completely reproduced, but the vector data, "roads," can be easily updated by adding the missing road segment. In addition, vector data allow much more analysis capability especially for "networks" such as roads, power, rail, telecommunications, etc. For example, with vector data attributed with the characteristics of roads, ports, and airfields, allows the analyst to query for the best route or method of transportation. In the vector data, the analyst can query the data for the largest port with an airfield within 60 miles and a connecting road that is at least two lane highway. Raster data will not have all the characteristics of the features it displays.

Voxel

Selected GIS additionally support the voxel data model. A voxel (a portmanteau of the words volumetric and pixel) is a volume element, representing a value on a regular grid in three dimensional space. This is analogous to a pixel, which represents 2D image data. Voxels can be interpolated from 3D point clouds (3D point vector data), or merged from 2D raster slices.

Non-spatial data

Additional non-spatial data can also be stored besides the spatial data represented by the coordinates of a vector geometry or the position of a raster cell. In vector data, the additional data are attributes of the object. For example, a forest inventory polygon may also have an identifier value and information about tree species. In raster data the cell value can store attribute information, but it can also be used as an identifier that can relate to records in another table.

Data capture

Data capture—entering information into the system—consumes much of the time of GIS practitioners. There are a variety of methods used to enter data into a GIS where it is stored in a digital format.

Existing data printed on paper or PET film maps can be digitized or scanned to produce digital data. A digitizer produces vector data as an operator traces points, lines, and polygon boundaries from a map. Scanning a map results in raster data that could be further processed to produce vector data.

Survey data can be directly entered into a GIS from digital data collection systems on survey instruments. Positions from a Global Positioning System (GPS), another survey tool, can also be directly entered into a GIS.

Remotely sensed data also plays an important role in data collection and consist of sensors attached to a platform. Sensors include cameras, digital scanners and LIDAR, while platforms usually consist of aircraft and satellites.

The majority of digital data currently comes from photo interpretation of aerial photographs. Soft copy workstations are used to digitize features directly from stereo pairs of digital photographs. These systems allow data to be captured in 2 and 3 dimensions, with elevations measured directly from a stereo pair using principles of photogrammetry. Currently, analog aerial photos are scanned before being entered into a soft copy system, but as high quality digital cameras become cheaper this step will be skipped.

Satellite remote sensing provides another important source of spatial data. Here satellites use different sensor packages to passively measure the reflectance from parts of the electromagnetic spectrum or radio waves that were sent out from an active sensor such as radar. Remote sensing collects raster data that can be further processed to identify objects and classes of interest, such as land cover.

When data is captured, the user should consider if the data should be captured with either a relative accuracy or absolute accuracy, since this could not only influence how information will be interpreted but also the cost of data capture.

In addition to collecting and entering spatial data, attribute data is also entered into a GIS. For vector data, this includes additional information about the objects represented in the system.

After entering data into a GIS, the data usually requires editing, to remove errors, or further processing. For vector data it must be made "topologically correct" before it can be used for some advanced analysis. For example, in a road network, lines must connect with nodes at an intersection. Errors such as undershoots and overshoots must also be removed. For scanned maps, blemishes on the source map may need to be removed from the resulting raster. For example, a fleck of dirt might connect two lines that should not be connected.

Raster-to-vector translation

Data restructuring can be performed by a GIS to convert data into different formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion.

More advanced data processing can occur with image processing, a technique developed in the late 1960s by NASA and the private sector to provide contrast enhancement, false colour rendering and a variety of other techniques including use of two dimensional Fourier transforms.

Since digital data are collected and stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert geographic data from one structure to another.

Projections, coordinate systems and registration

A property ownership map and a soils map might show data at different scales. Map information in a GIS must be manipulated so that it registers, or fits, with information gathered from other maps. Before the digital data can be analyzed, they may have to undergo other manipulations—projection and coordinate conversions for example, that integrate them into a GIS.

The earth can be represented by various models, each of which may provide a different set of coordinates (e.g., latitude, longitude, elevation) for any given point on the earth's surface. The simplest model is to assume the earth is a perfect sphere. As more measurements of the earth have accumulated, the models of the earth have become more sophisticated and more accurate. In fact, there are models that apply to different areas of the earth to provide increased accuracy (e.g., North American Datum, 1927 - NAD27 - works well in North America, but not in Europe). See Datum for more information.

Projection is a fundamental component of map making. A projection is a mathematical means of transferring information from a model of the Earth, which represents a three-dimensional curved surface, to a two-dimensional medium—paper or a computer screen. Different projections are used for different types of maps because each projection particularly suits certain uses. For example, a projection that accurately represents the shapes of the continents will distort their relative sizes. See Map projection for more information.

Since much of the information in a GIS comes from existing maps, a GIS uses the processing power of the computer to transform digital information, gathered from sources with different projections and/or different coordinate systems, to a common projection and coordinate system. For images, this process is called rectification.

Spatial Analysis with GIS

Data modeling

It is difficult to relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and high schools. A GIS, however, can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points. For example, a GIS can quickly generate a map with isopleths or contour lines that indicate differing amounts of rainfall.

Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlaid and analyzed with any other map in a GIS covering the same area.

Additionally, from a series of three-dimensional points, or digital elevation model, isopleths lines representing elevation contours can be generated, along with slope analysis, shaded relief, and other elevation products. Watersheds can be easily defined for any given reach, by computing all of the areas contiguous and uphill from any given point of interest. Similarly, an expected thalweg of where surface water would want to travel in intermittent and permanent streams can be computed from elevation data in the GIS.

Topological modeling

In the past years, were there any gas stations or factories operating next to the swamp? Any within two miles (3 km) and uphill from the swamp? A GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modeling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

Networks

If all the factories near a wetland were accidentally to release chemicals into the river at the same time, how long would it take for a damaging amount of pollutant to enter the wetland reserve? A GIS can simulate the routing of materials along a linear network. Values such as slope, speed limit, or pipe diameter can be incorporated into network modeling in order to represent the flow of the phenomenon more accurately. Network modeling is commonly employed in transportation planning, hydrology modeling, and infrastructure modeling.

Cartographic modeling

The "cartographic modeling" was (probably) coined by Dana Tomlin in his PhD dissertation and later in his book which has the term in the title. Cartographic modeling refers to a process where several thematic layers of the same area are produced, processed, and analyzed. Tomlin used raster layers, but the overlay method (see below) can be used more generally. Operations on map layers can be combined into algorithms, and eventually into simulation or optimization models.

Map overlay

The combination of two separate spatial data sets (points, lines or polygons) to create a new output vector data set. These overlays are similar to mathematical Venn diagram overlays. A union overlay combines the geographic features and attribute tables of both inputs into a single new output. An intersect overlay defines the area where both inputs overlap and retains a set of attribute fields for each. A symmetric difference overlay defines an output area that includes the total area of both inputs except for the overlapping area.

Data extraction is a GIS process similar to vector overlay, though it can be used in either vector or raster data analysis. Rather than combining the properties and features of both data sets, data extraction involves using a "clip" or "mask" to extract the features of one data set that fall within the spatial extent of another data set.

In raster data analysis, the overlay of data sets is accomplished through a process known as "local operation on multiple rasters" or "map algebra," through a function that combines the values of each raster's matrix. This function may weigh some inputs more than others through use of an "index model" that reflects the influence of various factors upon a geographic phenomenon.

Automated cartography

Digital cartography and GIS both encode spatial relationships in structured formal representations. GIS is used in digital cartography modeling as a (semi) automated process of making maps, so called Automated Cartography. In practice, it can be a subset of a GIS, within which it is equivalent to the stage of visualization, since in most cases not all of the GIS functionality is used. Cartographic products can be either in a digital or in a hardcopy format. Powerful analysis techniques with different data representation can produce high-quality maps within a short time period. The main problem in Automated Cartography is to use a single set of data to produce multiple products at a variety of scales, a technique known as Generalization.

Geostatistics

Geostatistics is a point-pattern analysis that produces field predictions from data points. It is a way of looking at the statistical properties of those special data. It is different from general applications of statistics because it employs the use of graph theory and matrix algebra to reduce the number of parameters in the data. Only the second-order properties of the GIS data are analyzed.

When phenomena are measured, the observation methods dictate the accuracy of any subsequent analysis. Due to the nature of the data (e.g. traffic patterns in an urban environment; weather patterns over the Pacific Ocean), a constant or dynamic degree of precision is always lost in the measurement. This loss of precision is determined from the scale and distribution of the data collection.

To determine the statistical relevance of the analysis, an average is determined so that points (gradients) outside of any immediate measurement can be included to determine their predicted behavior. This is due to the limitations of the applied statistic and data collection methods, and interpolation is required in order to predict the behavior of particles, points, and locations that are not directly measurable.

Interpolation is the process by which a surface is created, usually a raster data set, through the input of data collected at a number of sample points. There are several forms of interpolation, each which treats the data differently, depending on the properties of the data set. In comparing interpolation methods, the first consideration should be whether or not the source data will change (exact or approximate). Next is whether the method is subjective, a human interpretation, or objective. Then there is the nature of transitions between points: are they abrupt or gradual. Finally, there is whether a method is global (it uses the entire data set to form the model), or local where an algorithm is repeated for a small section of terrain.

Interpolation is a justified measurement because of a Spatial Autocorrelation Principle that recognizes that data collected at any position will have a great similarity to, or influence of those locations within its immediate vicinity.

Digital elevation models (DEM), triangulated irregular networks (TIN), Edge finding algorithms, Theissen Polygons, Fourier analysis, Weighted moving averages, Inverse Distance Weighted, Moving averages, Kriging, Spline, and Trend surface analysis are all mathematical methods to produce interpolative data.

Address Geocoding

Geocoding is calculating spatial locations (X,Y coordinates) from street addresses. A reference theme is required to geocode individual addresses, such as a road centerline file with address ranges. The individual address locations are interpolated, or estimated, by examining address ranges along a road segment. These are usually provided in the form of a table or database. The GIS will then place a dot approximately where that address belongs along the segment of centerline. For example, an address point of 500 will be at the midpoint of a line segment that starts with address 1 and ends with address 1000. Geocoding can also be applied against actual parcel data, typically from municipal tax maps. In this case, the result of the geocoding will be an actually positioned space as opposed to an interpolated point.

It should be noted that there are several (potentially dangerous) caveats that are often overlooked when using interpolation. See the full entry for Geocoding for more information.

Various algorithms are used to help with address matching when the spellings of addresses differ. Address information that a particular entity or organization has data on, such as the post office, may not entirely match the reference theme. There could be variations in street name spelling, community name, etc. Consequently, the user generally has the ability to make matching criteria more stringent, or to relax those parameters so that more addresses will be mapped. Care must be taken to review the results so as not to erroneously map addresses incorrectly due to overzealous matching parameters.

Reverse geocoding

Reverse geocoding is the process of returning an estimated street address number as it relates to a given coordinate. For example, a user can click on a road centerline theme (thus providing a coordinate) and have information returned that reflects the estimated house number. This house number is interpolated from a range assigned to that road segment. If the user clicks at the midpoint of a segment that starts with address 1 and ends with 100, the returned value will be somewhere near 50. Note that reverse geocoding does not return actual addresses, only estimates of what should be there based on the predetermined range.

Data output and cartography

Cartography is the design and production of maps, or visual representations of spatial data. The vast majority of modern cartography is done with the help of computers, usually using a GIS. Most GIS software gives the user substantial control over the appearance of the data.

Cartographic work serves two major functions:

First, it produces graphics on the screen or on paper that convey the results of analysis to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events. Web Map Servers facilitate distribution of generated maps through web browsers using various implementations of web-based application programming interfaces(AJAX, Java, Flash, etc).

Second, other database information can be generated for further analysis or use. An example would be a list of all addresses within one mile (1.6 km) of a toxic spill.

Graphic display techniques

Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of land surface with contour lines; the actual shape of the land can be seen only in the mind's eye.

Today, graphic display techniques such as shading based on altitude in a GIS can make relationships among map elements visible, heightening one's ability to extract and analyze information. For example, two types of data were combined in a GIS to produce a perspective view of a portion of San Mateo County, California.

The digital elevation model, consisting of surface elevations recorded on a 30-meter horizontal grid, shows high elevations as white and low elevation as black.
The accompanying Landsat Thematic Mapper image shows a false-color infrared image looking down at the same area in 30-meter pixels, or picture elements, for the same coordinate points, pixel by pixel, as the elevation information.

A GIS was used to register and combine the two images to render the three-dimensional perspective view looking down the San Andreas Fault, using the Thematic Mapper image pixels, but shaded using the elevation of the landforms. The GIS display depends on the viewing point of the observer and time of day of the display, to properly render the shadows created by the sun's rays at that latitude, longitude, and time of day.

Spatial ETL

Spatial ETL tools provide the data processing functionality of traditional Extract, Transform, Load (ETL) software, but with a primary focus on the ability to manage spatial data. They provide GIS users with the ability to translate data between different standards and proprietary formats, whilst geometrically transforming the data en-route.

GIS software

Geographic information can be accessed, transferred, transformed, overlaid, processed and displayed using numerous software applications. Within industry commercial offerings from companies such as ESRI and Mapinfo dominate, offering an entire suite of tools. Government and military departments often use custom software, open source products, such as Gram++, GRASS, or more specialized products that meet a well-defined need. Free tools exist to view GIS datasets and public access to geographic information is dominated by online resources such as Google Earth and interactive web mapping.

Originally up to the late 1990s, when GIS data was mostly based on large computers and used to maintain internal records, software was a stand-alone product. However with increased access to the Internet and networks and demand for distributed geographic data grew, GIS software gradually changed its entire outlook to the delivery of data over a network. GIS software is now usually marketed as combination of various interoperable applications and APIs.

Data creation

GIS processing software is used for the task of preparing data for use within a GIS. This transforms the raw or legacy geographic data into a format usable by GIS products. For example an aerial photograph may need to be stretched using photogrammetry so that its pixels align with longitude and latitude gradations. This can be distinguished from the transformations done within GIS analysis software by the fact that these changes are permanent, more complex and time consuming. Thus, a specialized high-end type of software is generally used by a skilled person in GIS processing aspects of computer science for digitization and analysis. Raw geographic data can be edited in many standard database and spreadsheet applications and in some cases a text editor may be used as long as care is taken to properly format data.

A geo-database is a database with extensions for storing, querying, and manipulating geographic information and spatial data.

Management and analysis

GIS analysis software takes GIS data and overlays or otherwise combines it so that the data can be visually analysed. It can output a detailed map, or image used to communicate an idea or concept with respect to a region of interest. This is usually used by persons who are trained in cartography, geography or a GIS professional as this type of application is complex and takes some time to master. The software performs transformation on raster and vector data sometimes of differing datums, grid system, or reference system, into one coherent image. It can also analyse changes over time within a region. This software is central to the professional analysis and presentation of GIS data. Examples include the ArcGIS family of ESRI GIS applications, Smallworld, Gram++ and GRASS.

Statistical

GIS statistical software uses standard database queries to retrieve data and analyse data for decision making. For example, it can be used to determine how many persons of an income of greater than 60,000 live in a block. The data is sometimes referenced with postal codes and street locations rather than with geodetic data. This is used by computer scientists and statisticians with computer science skills, with an objective of characterizing an area for marketing or governing decisions. Standard DBMS can be used or specialized GIS statistical software. These are many times setup on servers so that they can be queried with web browsers. Examples are MySQL or ArcSDE.

Readers

GIS readers are computer applications that are designed to allow users to easily view digital maps as well as view and query GIS-managed data. By definition, they usually allow very little if any editing of the map or underlying map data. Readers can be normal standalone applications that need to be installed locally, though they are often designed to connect to data servers over the Internet to access the relevant information. Readers can also be included as an embedded application within a web page, obviating the need for local installation. Readers are designed to be relatively simple and easy to use as well as free.

Web API

This is the evolution of the scripts that were common with most early GIS systems. An Application Programming Interface (API) is a set of subroutines designed to perform a specific task. GIS APIs are designed to manage GIS data for its delivery to a web browser client from a GIS server. They are accessed with commonly used scripting language such as VBA or JavaScript. They are used to build a server system for the delivery of GIS that is to make available over an Intranet.

Distributed GIS

Distributed GIS concerns itself with Geographical Information Systems that do not have all of the system components in the same physical location. This could be the processing, the database, the rendering or the user interface. Examples of distributed systems are web-based GIS, Mobile GIS, Corporate GIS and GRID computing.

Mobile GIS

GIS has seen many implementations on mobile devices. With the widespread adoption of GPS, GIS has been used to capture and integrate data in the field.

Open-source GIS software

Many GIS tasks can be accomplished with open-source GIS software, which are freely available over Internet downloads. With the broad use of non-proprietary and open data formats such as the Shape File format for vector data and the Geotiff format for raster data, as well as the adoption of OGC standards for networked servers, development of open source software continues to evolve, especially for web and web service oriented applications. Well-known open source GIS software includes GRASS GIS, Quantum GIS, MapServer, uDig, OpenJUMP, gvSIG and many others. PostGIS provides an open source alternative to geo-databases such as Oracle Spatial, and ArcSDE.

The future of GIS

Many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will result in a much wider use of the technology throughout science, government, business, and industry. The GIS applications including public health, crime mapping, national defense, sustainable development, agriculture, rural development, natural resources, landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services (LBS). LBS allows GPS enabled mobile devices to display their location in relation to fixed assets (nearest restaurant, gas station, police station), mobile assets (friends, children, police car) or to relay their position back to a central server for display or other processing. These services continue to develop with the increased integration of GPS functionality with increasingly powerful mobile electronics such as cell phones, PDAs, laptops.

Web Mapping

In recent years there has been an explosion of mapping applications on the web such as Google Maps, and Live Maps. These websites give the public access to huge amounts of geographic data with an emphasis on aerial photography. Some of them, like Google Maps, expose an API that enable users to create custom applications. These vendors' applications offer street maps and aerial/satellite imagery that support such features as geocoding, searches, and routing functionality.

Some GIS applications also exist for publishing geographic information on the web that include MapInfo's MapXtreme, Intergraph's GeoMedia WebMap, ESRI's ArcIMS, ArcGIS Server, AutoDesk's Mapguide and the open source MapServer.

Exploring Global Change with GIS

Maps have traditionally been used to explore the Earth and to exploit its resources. GIS technology, as an expansion of cartographic science, has enhanced the efficiency and analytic power of traditional mapping. Now, as the scientific community recognizes the environmental consequences of human activity, GIS technology is becoming an essential tool in the effort to understand the process of global change. Various map and satellite information sources can combine in modes that simulate the interactions of complex natural systems.

Through a function known as visualization, a GIS can be used to produce images - not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that literally never have been seen before. The images often are equally helpful in conveying the technical concepts of GIS study-subjects to non-scientists.

Adding the dimension of time

The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years.

As an example, the changes in vegetation through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic, known as a normalized vegetation index, represents a rough measure of plant health. Working with two variables over time would then allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation. GIS technology and the availability of digital data on regional and global scales enable such analyses. The satellite sensor output used to generate a vegetation graphic is produced by the Advanced Very High Resolution Radiometer (AVHRR). This sensor system detects the amounts of energy reflected from the Earth's surface across various bands of the spectrum for surface areas of about 1 square kilometer. The satellite sensor produces images of a particular location on the Earth twice a day. AVHRR is only one of many sensor systems used for Earth surface analysis

GIS and related technology will help greatly in the management and analysis of these large volumes of data, allowing for better understanding of terrestrial processes and better management of human activities to maintain world economic vitality and environmental quality.

Semantics and GIS

Tools and technologies emerging from the W3C's Semantic Web Activity are proving useful for data integration problems in information systems. Correspondingly, such technologies have been proposed as a means to facilitate interoperability and data reuse among GIS applications and also to enable new mechanisms for analysis.

Ontologies are a key component of this semantic approach as they allow a formal, machine-readable specification of the concepts and relationships in a given domain. This in turn allows a GIS to focus on the meaning of data rather than its syntax or structure. For example, reasoning that a land cover type classified as Deciduous Needle leaf Trees in one dataset is a specialization of land cover type Forest in another more roughly-classified dataset can help a GIS automatically merge the two datasets under the more general land cover classification. Very deep and comprehensive ontologies have been developed in areas related to GIS applications, for example the Hydrology Ontology developed by the Ordnance Survey in the United Kingdom. Also, simpler ontologies and semantic metadata standards are being proposed by the W3C Geo Incubator Group to represent geospatial data on the web.

Recent research results in this area can be seen in the International Conference on Geospatial Semantics and the Terra Cognita -- Directions to the Geospatial Semantic Web workshop at the International Semantic Web Conference.

GIS and Society

With the popularization of GIS in decision making, scholars have began to scrutinize the social implications of GIS. It has been argued that the production, distribution, utilization, and representation of geographic information are largely related with the social context. For example, some scholars are concerned that GIS may not be misused to harm the society. Other related topics include discussion on copyright, privacy, and censorship. A more optimistic social approach to GIS adoption is to use it as a tool for public participation.

Open Geospatial Consortium (OGC) standards

The Open Geospatial Consortium (OGC) is an international industry consortium of 334 companies, government agencies and universities participating in a consensus process to develop publicly available geo-processing specifications. Open interfaces and protocols defined by OpenGIS Specifications support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT, and empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications. Open Geospatial Consortium (OGC) protocols include Web Map Service (WMS) and Web Feature Service (WFS).

GIS products are broken down by the OGC into two categories, based on how completely and accurately the software follows the OGC specifications. Compliant Products are software products that comply with OGC's OpenGIS Specifications. When a product has been tested and certified as compliant through the OGC Testing Program, the product is automatically registered as "compliant" on this site.

Implementing Products are software products that implement OpenGIS Specifications but have not yet passed a compliance test? Compliance tests are not available for all specifications. Developers can register their products as implementing draft or approved specifications, though OGC reserves the right to review and verify each entry.

7.10. List of GIS software

Commercial or proprietary GIS software

Most widely used notable proprietary software applications and providers:

- ESRI – Products include ArcView 3.x, ArcGIS, ArcSDE, ArcIMS, and ArcWeb services.
- GRAM++ GIS – Low-cost GIS software product developed by CSRE, IIT Bombay.
- Autodesk – Products include MapGuide and other products that interface with its flagship AutoCAD software package.
- Cadcorp – Developers of GIS software and OpenGIS standard
- Intergraph – Products include GeoMedia, GeoMedia Profesional, GeoMedia WebMap
- ERDAS IMAGINE – A proprietary GIS, Remote Sensing, and Photogrammetry software developed by Leica Geosystems Geospatial Imaging.
- SuperGeo – Products include SuperGIS Desktop & extensions, SuperPad Suite, SuperWebGIS & extensions, SuperGIS Engine & extensions, SuperGIS Network Server and GIS services.
- SuperMap GIS – Products include SuperMap iServer .NET/Java, SuperMap Deskpro, SuperMap Objects, SuperMap Express, SuperMap IS .NET, eSuperMap, SuperNavigation Engine, FieldMapper and services.
- IDRISI – Proprietary GIS product developed by Clark Labs.
- MapInfo – Products include MapInfo Professional and MapXtreme. integrates GIS software, data and services.
- MapPoint – Proprietary GIS product developed by Microsoft.
- Caliper – Products include Maptitude, TransCAD and TransModeler. Develops GIS and the only GIS for transportation.
- Pictometry – Proprietary software which allows oblique images to be draped with shapefiles.
- Black Coral Inc — a leading edge product company developing geospatial collaboration capabilities that enable better outcomes for personnel and tactical teams operating in emergency response and military environments.
- STAR-APIC – european GIS developer, offers GIS products (WinSTAR, STAR GIS), spatial data servers (STAR Server, STAR NeXt, GEOSPatial Hub), GIS-based business solutions (AquaSTAR, STAR ELEC, PipeGuardian, etc.).
- CARIS (Computer Aided Resource Information System) – GIS systems for hydrography and cadastral systems.
- GMS – Three-dimensional environment for building geologic and groundwater models
- Manifold System – Low-cost GIS software package.
- Oracle Spatial – Product allows users to perform basic geographic operations and store common spatial data types in a native Oracle environment.
- Orbit GIS Generic and multi-purpose GIS toolkit, written in Java.
- Safe Software – Spatial ETL products including FME, SpatialDirect and the ArcGIS Data Interoperability Extension.
- Smallworld – developed in Cambridge

- TatukGIS – Products include a GIS development toolkit, Internet Map Server, GIS Editor, free GIS Viewer, Aerial Imagery Corrector.
- Axpand – Proprietary GIS cartography product developed by Axes Systems. Modules include data import/export, automatic generalization, visualization and on-screen editing, pre-print configuration.

Open source software

Most widely used open source applications:

- GRASS – Originally developed by the U.S. Army Corps of Engineers, open source: a complete GIS
- MapServer – Web-based mapping server, developed by the University of Minnesota.
- Chameleon – Environments for building applications with MapServer.
- GeoNetwork opensource – A catalog application to manage spatially referenced resources
- GeoTools – Open source GIS toolkit written in Java, using Open Geospatial Consortium specifications.
- gvSIG – Open source GIS written in Java.
- ILWIS – ILWIS (Integrated Land and Water Information System) integrates image, vector and thematic data.
- JUMP GIS – Java Unified Mapping Platform.
- MapWindow GIS – Free, open source GIS desktop application and programming component.
- OpenLayers – open source AJAX library for accessing geographic data layers of all kinds, originally developed and sponsored by MetaCarta
- PostGIS – Spatial extensions for the open source PostgreSQL database, allowing geospatial queries.
- Quantum GIS – QGIS is a user friendly Open Source GIS that runs on Linux, Unix, Mac OSX, and Windows.
- TerraView – GIS desktop that handles vector and raster data stored in a relational or geo-relational database.

Other GIS software

- AccuGlobe – Fully functional GIS and geoanalysis software platform for Windows developed by DDTI (ddti.net) and available free of charge, but not open source.
- CrossView for ArcGIS – created by A-Prime Software, CrossView is a wizard-based ArcGIS plug-in, which enables map cross-sectioning and profile creation.
- GeoBase – Geospatial platform developed by Telogis. A particular focus is placed on real-time processing for reverse-geocoding, geofencing, etc.
- LandSerf – Free GIS written in Java
- My World GIS – Intuitive low-cost GIS platform for Windows and Mac OSX with robust/intuitive geoprocessing tools, developed for educational.
- Panorama – Russian GIS for military uses.
- SPRING – GIS software developed at INPE –
- SavGIS – Free and complete GIS software available in French, English and Spanish

- MapTools – Suite of open-source GIS products and platforms.
- OpenStreetMap – Online map viewer, with map editing capability.

Summing Up

Geographical Information System (GIS) is the most important and useful system for decision making in Agricultural sector by the functionaries. GIS will help to ascertain the ground level realities with the help of spatial data obtained from various resources. In GIS one can integrate data from various sources such as Remote Sensing Data and Image with that of data of land records and agricultural census. It would be more appropriate to use GIS applications in agro-based enterprise to ascertain the scope of activities and monitoring of activities.

Remote Sensing Technology

Introduction

Remote Sensing (RS) is a technology that provides the means to collect and use geographic data to assist in the development of Agriculture. Remote Sensing in the most generally accepted meaning refers to instrument-based techniques employed in the acquisition and measurement of spatially organized or geographically distributed data on some properties such as spectral, spatial, physical of an array of target points of objects and materials from a define distance from the observed target. Remote sensing of the environment by geographers is usually done with the help of mechanical devices known as remote sensors. These gadgets have a greatly improved ability to receive and record information about an object without any physical contact. Often, these sensors are positioned away from the object of interest by using helicopters, planes, and satellites. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces.

Remote sensing imagery has many applications in mapping land use and cover, agriculture, soils mapping, forestry, city planning, archaeological investigations, military observation, and geological surveying.

Overview of Remote Sensing Technology

Remote Sensing is the technology that is now the principal tool by which the Earth's surface and atmosphere, the planets, and the entire Universe are being observed, measured, and interpreted from such vantage points as the terrestrial surface, earth-orbit, and outer space. The term "remote sensing" was coined by Ms Evelyn Pruitt in the mid-1950's when she was working with the U.S. Office of Naval Research (ONR) outside Washington, D.C as a oceanographer.

Remote Sensing is the most generally accepted meaning refers to "Instrument-based techniques employed in the acquisition and measurement of spatially organized data/information on some properties such as spectral, spatial, physical of an array of target points within the sensed scene that correspond to features, objects, and materials, doing this by applying one or more recording devices not in physical, intimate contact with the item(s) from at a finite distance from the observed target, in which the spatial arrangement is preserved. Various techniques involve pertinent to the sensed scene (target) by utilizing electromagnetic radiation, force fields, or acoustic energy sensed by recording cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, sound detectors, seismographs, magnetometers, gravimeters, scintillometers, and other instruments.

In simpler terms, Remote Sensing can be defined as "gathering data and information about the physical 'world' by detecting and measuring signals composed of radiation, particles, and fields emanating from objects located beyond the immediate vicinity of the sensor devices".

In the broadest sense, remote sensing is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing devices that is not in physical or intimate contact with the object such as by way of aircraft, spacecraft, satellite. In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area. Thus, Earth observation or weather satellite collection platforms, ocean and atmospheric observing weather buoy platforms, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and space probes are all examples of remote sensing. In modern usage, the term generally refers to the use of imaging sensor technologies including but not limited to the use of instruments aboard aircraft and spacecraft, and is distinct from other imaging-related fields such as medical imaging.

There are two kinds of remote sensing. (1) Passive sensors detect natural energy / radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared, and radiometers. (2) Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a passive sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speed and direction of an object.

Remote sensing makes it possible to collect data on inaccessible areas. Remote sensing applications include monitoring deforestation, the effects of climate change on Arctic and Antarctic regions, coastal and ocean depths, availability of water in the ground, and many more.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides researchers with enough information to monitor trends such natural long and short term phenomena. Other uses include different areas of the earth sciences such as natural resource management, agricultural fields such as land usage and conservation, national security, ground-based and stand-off collection on border areas.

History of Remote Sensing

Beyond the primitive methods of remote sensing our earliest ancestors used to standing on a high mountains or tree to view the landscape. The modern discipline arose with the development of flight. The balloonist made photographs of cities from their balloons. The first tactical use was during the civil war. Messenger pigeons, kites, rockets and unmanned balloons were also used for early images. With the exception of balloons, these first, individual images were not particularly useful for map making or for scientific purposes.

Systematic aerial photography was developed for military use beginning in World War I and reaching a climax during the Cold War with the use of modified combat aircraft. A more recent development is that of increasingly smaller sensor pods such as those used by law enforcement and the military, in both manned and unmanned platforms. The advantage of this approach is that this requires minimal modification to a given airframe. Later imaging technologies would include Infra-red, conventional, doppler and synthetic aperture radar

The development of artificial satellites in the latter half of the 20th century allowed remote sensing to progress to a global scale as of the end of the cold war. Instrumentation aboard various Earth observing and weather satellites such as Landsat, the Nimbus and more recent missions such as RADARSAT and UARS provided global measurements of various data for civil, research, and military purposes. Space probes to other planets have also provided the opportunity to conduct remote sensing studies in extra-terrestrial environment, synthetic aperture radar aboard the Magellan spacecraft provided detailed topographic maps of Venus.

Recent developments include, beginning in the 1960s and 1970s with the development of image processing of satellite images. Several research groups in Silicon Valley including NASA, developed Fourier transform techniques leading to the first notable enhancement of imagery data.

The introduction of online web services for easy access to remote sensing data in the 21st century mainly low/medium-resolution images, like Google Earth, has made remote sensing more familiar to the every one and has popularized the science.

Data acquisition techniques

Electromagnetic Radiation

Remote sensing is the practice of measuring an object or a phenomenon without being in direct contact with it. It is non-intrusive. This requires the use of a sensor situated remotely from the target of interest. A sensor is the instrument (camera) that takes the remote measurements. There are many different types of sensors, but almost all of them share something what they "sense" or take measurements of is usually Electro-Magnetic Radiation (EMR) or light energy. EMR is energy propagated through space in the form of tiny energy packets called photons that exhibit both wave-like and particle-like properties. Unlike other modes of energy transport, such as conduction (heating a metal skillet) or convection (flying a hot air balloon), radiation (as in EMR) is capable of propagating through the vacuum of space. The speed of that EMR in a vacuum (outer space) is approximately 300,000 kilometers per second (3 x 108 meters/second-1 or 186,000 miles/second-1). This is an extremely fast communications medium with visible light with its red, green, and blue colors that we see daily are an example of EMR. But there is a much larger spectrum of such energy. We often characterize this spectrum or range in terms of the wavelengths of different kinds of EMR. For a variety of reasons, there are some wavelengths of EMR that are more commonly used in remote sensing than other wavelengths.

Recording Electromagnetic Radiation

There are two broad categories of sensor systems used in remote sensing — active and passive. Passive sensors rely on EMR from existing sources, most commonly the Sun. Due to the extreme temperatures and nuclear activity on the surface of the Sun, this massive energy source emits a broad and continuous range of EMR, of which visible light is only a small fraction. EMR emitted from the Sun travels through the vacuum of space, interacts with the atmosphere, and reflects off objects and phenomena on Earth's surface. That EMR must again interact with the atmosphere before arriving at a remote sensor system in the air or in orbit. Some of the Sun's energy is absorbed by target objects such as water, rocks etc. on the surface of Earth and these are often heated as a result. Absorbed energy can then be re-emitted at longer wavelengths. Certain passive sensor systems are designed to record portions of this emitted energy.

On the other hand, active sensors themselves generate the EMR that they need to remotely sense objects or phenomena. The active sensors' EMR propagates from the sensor, interacts with the atmosphere, arrives at target objects trees, rocks, buildings, etc., interacts with these objects, and must be reflected in order to travel back through the atmosphere and be recorded at the sensor. Generally there are two types of active sensors:

A. Radar (Radio Detection and Ranging), which utilizes microwave energy, and
B. LiDAR (Light Detection And Ranging), which utilizes near-infrared or visible energy.

Reflectance of Electromagnetic Energy

Remote sensing would be of little use if every object or phenomenon on Earth behaved in exactly the same way when interacting with EMR. Fortunately, different objects reflect portions of the electromagnetic spectrum with differing degrees of efficiency. Similarly, different objects emit previously absorbed EMR with differing degrees of efficiency. In the visible spectrum these differences in reflective efficiency account for the myriad of colors that we see. For example, green plants appear of that color because they reflect greater amounts of green light than of blue or red light. Plotting the spectral reflectance levels of a given object or phenomenon by wavelength yields a spectral reflectance curve, or spectral signature. This signature is the remote sensing key to distinguishing between one type of target and another. For example, the signature of a deciduous tree is entirely different that of an evergreen tree.

Analog or Film-based Sensors

Today we hear the terms analog and digital when referring to a wide range of electronic devices. In general, analog devices operate using dynamic physical properties (e.g., chemical changes) while digital devices operate using numbers (0s and 1s). Remote sensor systems record patterns in incoming EMR using analog detectors. While all remote sensor systems have at least a partial complement of analog components, some sensor systems are completely analog. A prime example of this is a film-based aerial camera. The emulsion of silver halide crystals in film responds chemically to EMR exposure. Further analog processing is used to generate negative and positive transparencies and hardcopy photographs.

In an analog aerial camera, the length of exposure to incoming EMR is controlled through a shutter that opens for just a fraction of a second. While the shutter is open, the incoming light is focused on the film plane at the back of the camera using a high quality lens. With each exposure, the focused image of EMR causes a lasting chemical change to the exposed portion of film and a new unexposed section of film is needed in order to repeat the process.

A film-based camera used for remote sensing differs in a few ways from a typical camera used for photography. For one thing, the film itself is much larger (nine inches wide). For another, the camera's focal length is much longer (about 175 mm). Without delving in detail into the science of photography, these differences allow the aerial camera to take better, larger-scale photographs even from a moving platform. Most cameras designed for this purpose are metric, meaning that their internal dimensions have been precisely calibrated and are reported to the user. This is vital to the practice of photogrammetry or taking detailed measurements on photographic maps.

Digital Sensors

Digital sensors also measure patterns in incoming EMR using analog detectors. However, measurements of EMR taken by each detector element are recorded, not using an analog medium such as film, but using numbers. These measurements are digitized through a process called analog-to-digital (A-to-D) conversion. Possible values are in a pre-defined range, such as 0 to 255. Each recorded numerical value is then stored on some kind of digital medium, such as a hard disk, as part of a raster dataset. The value in each raster cell represents the amount of energy received at the sensor from a particular circular area, instantaneous-field-of-view (IFOV) on the ground. Digital sensors make use of the same basic technology as a computer document scanner or a digital camera. In fact, specialized digital cameras are often used to acquire remote sensor data and professional-grade document scanners are often used to convert analog remote sensing data to digital data.

The detectors in a digital sensor can be arranged in a number of different ways. One method utilizes a single detector for each frequency band. A scanning mirror is then used to capture EMR at each IFOV along a scan line. The forward motion of the sensor allows for additional scan lines and therefore a two dimensional image. This is type of instrument is often referred to as a scanning mirror sensor.

A second method is to have a linear array of detectors for each band. Each detector in an array records EMR for a single IFOV in the cross-track dimension i.e., perpendicular to the direction of flight. The forward motion of the sensor again allows for repeated measurements and two-dimensional imagery. This type of sensor system is often called a linear array push-broom scanner. Push-broom systems have several advantages over scanning mirror sensors. They have fewer moving parts, so they are generally more durable. Also, the process of assigning coordinates to push-broom data is much easier.

A third digital sensor configuration is the one that is most like the operation of analog film-based systems. In this case, an entire area array is placed at the back of the sensor. Energy is focused through a lens onto this bank of detectors. These types of sensors are called digital cameras, or area array sensors. They are often used in similar applications as film-based cameras.

Types of Resolution

Resolution quantifies how distinguishable the individual parts of an object or phenomenon are. When discussing the specifications of remote sensor systems, we generally speak of four different types of resolution.

A. Temporal Resolution

Temporal resolution is how often a sensor visits, or can visit, a particular site to collect data. This is important because many applications depend on observing change in phenomena over time. A remote sensing instrument is mounted on a platform such as a satellite, an aircraft, a hot air balloon. The platform on which a sensor is mounted is the greatest determinant of that sensor's temporal resolution.

Some satellites orbit Earth without ever approaching its shadow - that is, they are in Sun-synchronous orbit. Other satellites maintain a fixed position above the rotating Earth - these are in geo-synchronous orbit. In either case, these satellites have a regular and predictable temporal resolution (every 16 days). Some satellite-based sensors are more flexible than other ones because of their ability to point at various targets near their default field-of-view. These more flexible sensors may have a temporal resolution range (2-3 days). Sensors mounted on aircraft fly ad-hoc or on-demand missions with less predictable but more flexible temporal resolution (every hour).

B. Spatial Resolution

Spatial resolution describes the size of the individual measurements taken by the remote sensor system. This concept is closely related to scale. With an analog sensor, such as film, the spatial resolution is commonly expressed in the same terms as the scale (e.g., 1:500). Since digital sensor records information in raster format the spatial resolution is the cell size (e.g., 3 x 3 meters) in ground units.

C. Spectral Resolution

Spectral resolution describes the sensor systems' ability to distinguish different portions of the EMR spectrum. Some sensors are sensitive to visible light only, while others can also capture near-infrared energy. The portions of the spectrum to which an instrument is sensitive are referred to as its bands. A sensor can have multiple bands, and bands can be of varying widths. Spectral resolution refers both to the number and width of the bands for a given sensor.

A panchromatic band is a wide band that encompasses a large spectral range, often the entire visible spectrum. Commonly we call film that is sensitive to the entire visible range "black and white" film because often we print images from this sort of film in grayscale. However, there are analog and digital sensors that have wide panchromatic bands that also encompass the near infrared portion of the spectrum.

When a sensor records only a few portions of the spectrum i.e., contains only a few, relatively wide bands, it is said to be a multispectral system. A multispectral sensor might have two or three bands in the visible range i.e. red, green, and blue and it might also have a few near-infrared or middle infrared bands. Typical multispectral systems have between 4 and 10 bands.

Hyperspectral sensors have a large number of relatively narrow bands. By definition, hyperspectral sensors have a higher spectral resolution than multispectral sensors. Commonly a sensor is considered hyperspectral when it has at least 20 or 30 bands. Many such sensors have hundreds of bands. In general, a sensor with more spectral bands has a greater ability to distinguish between two objects with similar spectral properties.

Each band in a digital dataset can be thought of as an individual raster layer. Visualize an image in three dimensions, with rows, columns, and bands filling the x, y, and z coordinates of a cube.

D. Radiometric Resolution

Radiometric resolution describes the number of unique values that can be recorded by a sensor system when measuring reflected or emitted EMR. In a digital system this is easily quantified as a number. Since the digital numbers in remote sensor data are stored in a computer, they are often expressed in terms of how many bits are used to store that variety of numbers (Ex., 8-bits, 11-bits). An 8-bit sensor would store a value for each measurement in an integer range from 0 to 255. This range has 28-256 discrete values. With analog, or film-based, systems it is the quality of the film that determines its radiometric resolution.

Converting Remote Sensing Data into Geospatial Data

Remote sensing applications are rarely successful without at least some direct measurements / ground truth being taken within the area. However, "truth" is really a misnomer since there is always at least some error in measurements, even if they are taken directly. "Ground reference" would be a better descriptor. A correct term for measurements taken directly as opposed to remote measurements is in situ data collection. Several types of in situ measurements may be necessary for a given project or application. Almost all remote sensing projects require some amount of in situ data collection in order to perform geometric and radiometric calibration. Additional in situ data may be required to create reference maps of spatial variables, including biophysical properties.

Geometric Correction

When remote sensor data is initially collected it is not geospatial data. In order to make the transition to geospatial data, geometric correction must be applied to make the data into a real-world coordinate system. Beyond having no real-world coordinates assigned, the raw data also contains geometric distortion. This means that all of the objects or phenomena that can be seen in the data are not equally out of place relative to a desired coordinate system. Distortion generally increases away from the point in the data that were acquired at straight down. Distortion is therefore different depending on the sensor configuration (Ex., scanning mirror sensors vs. area array digital cameras). Another source of distortion are variations in the terrain and objects on the terrain. Tall objects and steeply sloping terrain lead to more distortion than flat objects on flat terrain.

A basic method for geometric correction involves the use of a GPS receiver in the field. GPS measurements are taken at locations that are also easily identifiable in the imagery. These types of locations will vary according to the spatial resolution of the remote sensor data. Ideally the smallest possible features that can be visualized in that data should be located in the field and their positions surveyed. These features should also be permanently situated. The recorded locations of these features in the study area are collectively known as control points. Road intersections typically make good control points. Features above the ground surface do not make good control points because they cause distortion. Control points should be collected at locations spaced evenly throughout the remote sensor image. In fact, the relative location of the control points is at least as important as the number of points.

Once enough control points have been collected, they can be used to adjust the data to its approximate spatial position within a coordinate system. Most geospatial software packages provide an interface for doing this. As part of the process, the software package will typically report a number indicating the degree to which the desired transformation was successfully implemented. The success rate depends on the amount of distortion present in the raw data. Once the remote sensor data has undergone this process it is said to be georectified data.

Photogrammetry Correction

In order to create an image that is free from all major distortions, the terrain and sensor-induced distortions must be accounted for explicitly. This is done by using a combination of GPS control points, a digital elevation model (DEM), and a detailed report of the distortion present in the sensor system. When data has been corrected in this manner it is said to be orthorectified. In an orthorectified image, all points are in their proper x, y position and aligned as they would appear if one were looking straight down at them.

The practice of orthorectification is part of photogrammetry — the art of taking direct measurements from photos and other remotely sensed data. Measurements derived using photogrammetric techniques include the height of objects on the terrain, their x, y location, and the ground distance between objects.

Radiometric Correction

In addition to geometric distortion, EMR that is received by the sensor contains radiometric distortions. The source of these distortions is primarily the atmosphere and its dynamic constituents. If there were no atmosphere with which to contend, EMR recorded by the sensor would be a much more perfect representation of EMR reflected or emitted from the target object or phenomena. However, along the path between the target and the sensor, EMR must interact twice with the atmosphere. Some of this energy is scattered and some of it is absorbed. Atmospheric constitutes such as water vapor and pollution vary across space and time, and therefore these distortions make it particularly difficult to compare datasets collected at different times.

There are various ways to minimize this distortion. Between-date radiometric differences can be minimized if the datasets are collected at similar times so that the

Sun's position is held constant. Also, acquiring data on a clear day will minimize the amount of water vapor and clouds.

Even after taking these measures, many applications require additional radiometric correction to account for differences and distortions in the EMR values recorded at the sensor. This can be done in a few different ways, each with some degree of difficulty and level of uncertainty in the results. Following are three examples, of many that one could give.

One simple radiometric correction technique is to rescale all of the pixel brightness values in an image by identifying one of the darkest pixels and one of the brightest pixels. The darkest pixel is re-assigned a value of 0, and the lightest a value of 255. The intermediate values are then rescaled to fit evenly in between. Although this method is very easy and requires no additional input data, it is the least reliable. This technique is known as a min-max contrast stretch.

A second, simple method is referred to as empirical line calibration. In this method, several in situ radiometric measurements are taken over various objects concurrently with the acquisition of the remote sensor data. The instrument used for these measurements is called a radiometer. Unlike the remote sensor system, the radiometer is used to take measurements in situ with almost no atmosphere with which to contend. The data collected using the radiometer is used to develop a simple linear mathematical function to predict what the radiometric values should be over the entire image.

A third method is more complex than either of the previous two. It relies on collecting explicit information on the environmental conditions at the time of the remote sensor data acquisition. This information might include a detailed profile of temperature and humidity within the atmospheric column, the Sun-Earth geometry, and the position of the sensor with respect to each pixel. This method is actually a group of methods, each requiring differing information. Automated computer algorithms are then used to process the remote sensor data along with the ancillary data to produce a radiometrically-corrected image.

Visual Image Interpretation

With the power of the human visual system, much information in remote sensor data can be acquired simply by visual inspection. Examples include the spatial extent of a lake, the location of roads, and the number of houses in a community. These are all variables that can be "seen" on the terrain and interpreted directly by visualizing the imagery.

In these cases a trained image analyst uses a combination of real-world experience and heuristic rules-of-thumb to interpret what is seen in the image and to determine its significance. The process of image interpretation can be broken down into its fundamental elements, including:

- absolute location (coordinates)
- relative location
- size
- shape
- shadow
- tone/color
- texture
- pattern
- 3-dimensional characteristics
- Color Composites

White light from the Sun is composed of EMR from all wavelengths within the visible spectrum. We can see this clearly when white light passes through a prism and separates into a rainbow. Combining these colors of the rainbow back together yields white light. Adding only some portions of the rainbow light will result in a different color.

One can create any color by mixing the three primary ones — red, green, and blue (additive color theory). Each pixel in a computer screen is actually made using three different light "guns," one for each of these primary colors. These guns respond to commands by the computer to display with various intensities. The addition of the EMR emitted by these three guns determines what color the user perceives.

The initial visualization of remote sensor data is an important aspect of an effective interpretation effort. Digital remote sensor data is displayed by assigning recorded brightness values to the three colour guns mentioned above. When the red, green, and blue bands in the visible spectrum are assigned to their respective red, green, and blue color guns, the displayed result is said to be a true color composite. However, remote sensor systems often measure EMR outside the visible range, requiring the creation of false color composites. For example, near-infrared bands are often displayed using the red color gun. When looking at a false color composite image, special care needs to be taken to interpret it correctly.

Automated Classification

Although manual image interpretation is valuable and often provides highly detailed and accurate information, many applications require that objects on the ground be classified faster and more cost-effectively. In these cases it is necessary to automatically interpret, or classify, the image using computer algorithms.

There are primarily two different ways to approach this goal. Both are based on the simple concept that similar objects or phenomena have similar spectral reflectance properties. The first method is referred to as an unsupervised classification. In this method, the computer algorithm operates without any prior knowledge of the scene. Pixels are grouped together based on the similarity of their spectral characteristics. These clusters of similar pixels, representing unique spectral classes, are then reported to the user, who is responsible for transforming them into information classes. This process can be aided with in situ data and/or manual image interpretation.

Supervised classification, is the second method, requires that the user have some knowledge of the actual objects and phenomena within the image. This knowledge could have been acquired through in situ data collection or manual image interpretation. The user specifies the classes (Ex. water, forest, crops) and then instructs, or trains, a computer algorithm by feeding it the exact location of several training examples for each class throughout the image. The computer algorithm examines the properties of these areas and then seeks similar regions throughout the image, eventually classifying the entire image. Spectral data is often the primary data source considered in the process, although recently more effort has been made to incorporate more advanced aspects, such as object shape and relative position.

Mapping Spatial Variables

There are certain aspects of phenomena that must be sensed while in direct contact with an object. For example, it is impossible to directly measure the live biomass, the amount of living matter, present in a stand of vegetation without harvesting the vegetation, processing it to remove water and foreign substances, and then weighing it. However, it is possible for a trained person to estimate the biomass present in a particular stand of vegetation without coming in direct contact with it. In a similar manner, remote sensing principles provide a way to quantify what is "seen" and provide information, such as biomass or other biophysical variables, which are present in an image.

Mapping biomass requires taking some in situ measurements of the vegetation of interest. These measurements are used to build a mathematical model relating to the quantity of biomass to the spectral reflectance values in the remote sensor data. An example of this type of equation might be:

Biomass = Bias + (Constant A x Near-infrared) + (Constant B x Red)

In addition to using the band values directly, it has been shown that specific mathematical combinations of band values are effective for mapping various phenomena. For example, the Normalized Difference Vegetation Index (NDVI) is often highly related to a number of vegetation properties, including green biomass. There are many other band indices for use in vegetation, geologic, and other application areas.

Creating Elevation Data from Remote Sensing Data

Elevation is another example of a continuous variable that can be remotely sensed. This can be done in several different ways. One is through collecting stereoscopic pairs of images. In each pair, the images partially overlap. The fact that the two images are acquired from different positions allows us to extract 3D (2D plus height) information from the overlapping portion. This method is a branch of photogrammetry. The operating principle is closely related to how our eyes detect 3D information by combining the different images from our two eyes. In fact, stereoscopic pairs of remote sensor images can viewed through a device called a stereoscope, thus enabling the user to see the terrain in 3D. Today there are specialized computer software packages that allow users to make quantitative elevation calculations directly from stereoscopic imagery. When a large number of these measurements are taken, an elevation surface / DEM can be derived.

A second, related method is radar interferometry. Differences in radar signals acquired over the same area from different positions can be used to create an elevation surface.

A third method of deriving elevation data is to use LiDAR data. Most of the time, the collection of LiDAR data results in a series of x, y, z points. Once the points that have reflected off the ground are separated from those that reflected off other objects above the ground, a digital surface representing the ground can be created.

Old data from remote sensing is often valuable because it may provide the only long-term data for a large extent of geography. At the same time, the data is often complex to interpret, and bulky to store. Modern systems tend to store the data digitally, often with lossless compression. One of the best systems for archiving data series is as computer-generated machine-readable form. They can be created, copied, filed and retrieved by automated systems. They are about as compact as archival magnetic media, and yet can be read by human beings with minimal, standardized equipment.

Remote Sensing Software

The most used software in remote sensing are ESRI (Environmental Systems Research Institute), ERDAS, RSI ENVI, MapInfo, ERMapper, AutoDesk etc. The most free remote sensing software seems to be Chips (CopenHagen Image Processing System) for windows and a large number of popular Free and Open Source software options exist for remote sensing data analysis, ranging from programming APIs and toolkits like GDAL, to full featured desktop applications like GRASS GIS, and OpenEV.

Applications of Remote Sensing and GIS

Remote sensing is an important tool to provide important information on soils, land evaluation, land degradation, crop distribution, crop growth, availability of water resources etc. The information of Remote Sensing can be improved in its efficiency by combining with conventional technologies / ground surveys and also the advanced tools such as GIS for analysis and interpretation.

Remote sensing data is available in digital form and can be used as an input layer to GIS software. The software such as ArcInfo/ERDAS, which supports for both remote sensing and GIS data. The advent of technology in storage capacity, processing capabilities, relational databases, and enhanced graphical user interface has given more capabilities to work on remote sensing and GIS data for analysis and interpretation of data. Use of GIS in combination with remote sensing enhances the decision-making in following ways;

- Process identification to enable comparison of different acquisitions through time
- Identification of agricultural and other development problems
- Evaluation of possible technical interventions for conservation or reclamation measures.
- Monitoring of soils, water, and land degradation processes.

Crop Production Databases

Crop production database is used to know how many hectares have been cultivated, where the cultivation has occurred and how will be likely production of food i.e. Area and Production various crops can be assed with the help of remote sensing and GIS applications. Crop distribution help in modeling of climatic and other environmental changes and their effects on agriculture.

Crop growth and yield determination:

Crop growth and yield are determined by a number of factors such as genetic potential of crop cultivar, soil, weather, cultivation practices such as date of sowing, amount of irrigation and fertilizer and biotic stresses. However, generally for a given area, year-to-year yield variability has been mostly modeled through weather as a predictor using either empirical or crop simulation approach. With the launch and continuous availability of multi-spectral (visible, near-infrared) sensors on polar orbiting earth observation satellites remote sensing data has become an important tool for yield modeling. RS data provide timely, accurate, synoptic and objective estimation of crop growing conditions or crop growth for developing yield models and issuing yield forecasts at a range of spatial scales. RS data have certain advantage over meteorological observations for yield modeling, such as dense observational coverage, direct viewing of the crop and ability to capture effect of non-meteorological factors. An integration of the three technologies, viz., crop simulation models, RS data and GIS can provide an excellent solution to monitoring and modeling of crop at a range of spatial scales.

Crop monitoring

The use of GIS along with RS data for crop monitoring is an established approach in all phases of the activity, namely preparatory, analysis and output. In the preparatory phase GIS is used for (a) stratification/zonation using one or more input layers (climate, soil, physiolgraphy, crop dominance etc.), or (b) preparing input data (weather, soil and collateral data) which is available in different formats to a common format. In the analysis phase use of GIS is mainly through operations on raster layers of NDVI or computing VI profiles within specified administrative boundaries. The final output phase also involves GIS for aggregation and display of outputs for defined regions (e.g., administrative regions) and creating map output products with required data integration through overlays.

Summing Up

The use of remote sensing technology has been rapidly expanded for the development of all sectors that also includes Agriculture. The remote sensing techniques will continue to be very important factor in the improvement of present system of acquiring agricultural data. The remote sensing provides various platforms for agricultural survey. Satellite imagery has unique ability to provide the actual synoptic views of large area at a time, which is not possible for conventional survey methods and also the process of data acquisition and analysis are very fast through Geographic Information System as compared to the conventional methods. The importance of remote sensing applications with reference to agricultural sector involving land use pattern, crop production, crop yield determination, and crop monitoring.

MAPPING SOIL RESOURCES WITH REMOTE SENSING DATA

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Soil is at the heart of terrestrial ecology and is vital to our very existence. However, there is evidence to show that a majority of our soils are undergoing degradation at an unacceptable rate with risk of jeopardizing our food security for the future generations. For this purpose, we must have an in-depth knowledge about different soils, their morphology, physical and chemical properties, behaviour, kind and degree of problem and their extent and distribution on the landscape which can be achieved through soil survey and mapping. In this respect, the modern technology of space borne remote sensing, now operationally used for studying soil resources, proved to be a powerful tool, because it enables to study resources in spatial domain in time and cost effective manner.

SPECTRAL REFLECTANCE OF SOILS

In many applications of remote sensing in soils, understanding the principles of spectral reflectance of soils is fundamental and their limitation is crucial. The soil reflectance data can be acquired in the laboratory or in the field and from air / space. In the laboratory the soil reflectance measurements are made under controlled conditions which they may enable to understand the relationship between the physical and chemical properties of soil and soil reflectance. In the field, reflectance measurements are made with the help of portable field spectrometers / radiometers and field soil spectroscopy will help in rapid point to point measurement of soil properties. However, the measurements are effected by variations in viewing angle or illumination condition and roughness factors. In the case of soil reflectance from air / space, the soil reflectance values can be obtained over a large area and reflectance can be studied in spatial domain. But factors like low signal to noise ratio and atmospheric attenuations, become critical. Nevertheless, information about soils from reflectance spectra in the visible (0.4 µm to 0.7µm), near infrared (NIR – 0.7 to 1.1µm) and short wave infrared (SWIR- 1.1 to 2.5µm) regions of electromagnetic spectrum (EMS) represent almost all the data the passive remote sensors can provide. Even thermal infrared regions (3 to 5 µm and 8 to 12 µm) also provide diagnostic information about soils. Spectrometers, radiometers and polarimeters provide quantitative measurement of reflected energy from soil and have found applications in studying the various aspects of soils as mentioned previously.

The most important soil properties that influence the reflectance are soil moisture content, texture, structure and iron oxide content. These factors are interrelated and, the spectral reflectance of soil is a cumulative property of combination of these factors.

The shape and nature of a soil reflectance curve depends upon the physical and chemical properties of soils. The important physical properties are soil colour, soil texture, structure, soil moisture, surface conditions / roughness etc. The chemical properties of soils result in absorption of incident radiation and is seen on reflectance curve as troughs whose positions are attributed to specific chemical groups in various structural configurations. It includes soil mineralogy, organic matter salinity, carbonates etc.

Soil color is mostly influenced by mineralogy, chemical composition, soil moisture, and organic matter content. It is an important parameter as it allows the diagnosis of soil types and their properties, as well as the detection of changes affecting ecosystems like erosion, salinization and / alkalization. Several researchers observed that the visible and near infrared region are the most suitable spectral regions of EM spectrum for qualitative and quantitative description of soils.

Organic matter in soils has profound influence on soil spectral characteristics. The increase in organic matter has been found to result in a decrease in reflectance. The organic matter has effect on spectral reflectance of soils throughout the visible, NIR and SWIR region of EMS and many workers have studied organic matter extensively from a remote sensing point of view. The absorption features of reflectance spectra are related to functional groups in the organic matter and models were developed to predict the humus / organic carbon content in soils.

Particle size or soil texture (refers to relative proportions of sand, silt and clay in soil) is another soil property that influences the spectral reflectance of soils significantly. Finer the particle size, the soil becomes smooth and more incoming energy is reflected. An increase in particle size causes a decrease in reflectance. However, silt content of soil is considered as major controlling factor for spectral reflectance. The spectral reflectance decreases with decrease in silt content. However, it is commonly observed that sandy soil exhibits higher reflectance than that of clayey soil, which is due to abundance of macro pores and air-soil interface. Under field conditions the soil structure (refers to arrangement of sand, silt and clay particles into aggregates) play a dominant role in altering the reflectance from soil. Factors that contribute to change in aggregate size over a period of time are tillage, soil erosion, crust formation etc.

Soil minerals viz., clay mineralogy and iron and iron oxides have significant influence on the spectral reflectance pattern of soils. In literature it is reported that an increase in iron oxide content in soils can cause decrease in reflectance, in visible wavelengths. Many of the absorption features in soil reflectance spectra are due to the presence of iron in one or other form and provide significant evidence on soil weathering process. Soils dominant in ferrous and ferric ions i.e. Limonite, Hematite and Goethite exhibit high response in the red region of spectrum. The ferric ion response bands are approximately at 0.40, 0.70 and 0.87 µm and a sharp and narrow absorption band is evident at 0.9 µm. The ferrous ion on the other hand, has been found to respond at 0.43, 0.45, 0.51, 0.55 and 1.0 µm. Limonite shows typical bands at 0.9 um due to Ferric oxides and hydration bands near 1.4 um and 1.7 um. Muscovite displays hydroxyl bands at 1.4 um as well as between 2.2 um and 2.6 um. In addition, Biotite exhibits a very broad band in the 0.6 to 1.5 um region due to ferrous and ferric ions.

Clay minerals are layered crystalline aluminosilicate minerals, which are characterized by hydroxyl bands at 1.4 µm and 2.2 µm. Absence of appreciable amount of bound water in Kaolinite shows a weak band at 1.9 µm due to absence of appreciable amounts of bound water whereas montmorillonite shows very strong bands at 1.9 µm as well as at 1.4 µm. Quartz and feldspar show very high reflectance and the spectrum in the visible and near infrared is almost devoid of spectral features (such as absorption maxima denoted as bands) unless impurities occur. Carbonate response bands have been noticed at 1.90, 2.00, 2.16, 2.35 and 2.55 µm. Soils with Gypsic minerals have high reflectance because of the inherent reflectance properties of gypsum.

SOIL MAPPING

Satellite data from Indian Remote Sensing (IRS) sensors are being used to generate soil maps through monoscopic (non-stereoscopic) visual interpretation and computer-assisted digital analysis approaches. In visual Interpretation approach, the intimate relationship between physiography (landform) of the terrain and soils occurring therein is exploited. Lithological (parent material) units are initially delineated based on available geological maps. It is followed by delineation of broad physiographic units based on relief information available in topographical maps, and further sub-divisions of physiographic units taking into account land use / land cover, soil erosion, surface drainage, soil salinity and/or alkalinity as revealed in the image. Sample strips covering variations in terrain features and soils are then selected. Field visit is subsequently made to establish the relationship between image elements, namely tone, colour, texture, pattern, association, etc. and soils of the area. Apart from terrain features like length and degree of slope, land use / land cover, erosion hazards, surface drainage, etc., soil profile and auger-bore observations are taken in sample areas during field check, and soil samples are collected from profiles and auger-bores for analysis in the laboratory. Based on morphological and chemical analysis data soils are classified according to Soil Taxonomy. Modifications in the physiographic units, delineated earlier, are made. Physiographic (or landscape) units are subsequently translated into soilscape units by incorporating information on soils. Soilscape units are subsequently transferred onto base map of the same scale generated from Survey of India topographical maps.

The computer-assisted digital analysis is essentially based on the premise that the each object (here individual soil unit) could be characterized by its unique spectral response pattern. The approach consists of three stages, namely training stage, classification stage, and testing and validation stage. Establishing the relationship between these spectral classes and soils occurring therein by studying soil profiles and auger-bores in the field followed by chemical analysis in the laboratory, generating spectral response pattern (signature), assessing the spectral seperability, and labeling each pixel with a particular soil unit using either parametric (supervised classification) or non-parametric (un-supervised classification) approach encompasses the second stage. Multispectral data have been used for deriving information on soils after geometric and radiometric correction or various image enhancement techniques have been employed to improve the image contrast, and spectral soil maps have been prepared using supervised or un-supervised approach or a combination thereof. Computer-assisted digital approach was used to generate soil resources maps and to delineate salt-affected soils using Landsat-MSS and IRS-LISS data. Digital Elevation Model (DEM) generated from Cartosat-1 was also used along with Resourcesat multispectral data for delineation of soil resources.

The launch of the Indian Remote Sensing Satellite (IRS-1A, 1B, 1C, 1D) with sensors, namely Linear Imaging and Self-scanning Sensors (LISS-I, II, III) and Panchromatic (PAN) provided the backup for soil resources mapping and land degradation studies at 1:250,000, 1:50,000 and 1: 12500 scales. The multispectral data acquired during the period when soil is almost devoid of vegetation i.e. summer season, and when the vegetation cover is maximum, which coincides with the peak crop growing period, are ideal for soil resources mapping. Since land cover is used for delineation of sub-units within broad physiographic units. In India various operational projects of applications remote sensing techniques in soil resource studies were undertaken and successfully completed.

LAND DEGRADATION

As per World Resources Institute (1984) land degradation is the deterioration of soil, severely reduced productivity of desirable plants and declining diversity of flora and fauna because of the activities of both people and livestock. The study, published in 1994 as a report titled, 'Land degradation in South Asia', defined land degradation as 'the temporary or permanent lowering of the productive capacity of land.'

Remotely sensed data from satellites are being operationally used to derive information on degraded lands and monitor them periodically in time and space domain using multi temporal data in India (Venkataratnam and Rao, 1977; Venkataratnam, 1980, 1983, 1984, 1989; Venkataratnam and Ravisankar, 1992, Rao et al., 1991; Karale et al., 1988; NRSA, 1981; Singh et al., 1977, 1988; Sharma and Bhargava, 1987) and in other countries. In table-1.3 the methodologies used for land degradation assessment by different scientists / organizations are summarized along with the input data used, scale and output of their studies.

Table 1. Methodologies used for land degradation assessment

Authors Years	Input data used Source of Information	Criteria selected	Scale and output
Kassas 1987	Global climate, soil & vegetation maps	Extension of desert areas	Global figures
Dregne, 1977,	Global maps and	State of vegetation, state	Global/Continental,

1983, 1986	statistics	of soil erosion, state of salinization decrease of crop yields	statistical tables small scale maps
Tucker & Justice, 1986	NOAA (AVHRR)	Vegetation density & productivity	Regional Small scale maps
Pankova et al, 1986	Satellite images/ground surveys	Degree of soil salinity, soil salinity,	Statistical tables; Regional scale
Kovda et al, 1977, 1978	Small scale soil maps statistics, soil descriptions	Soil salinity, degree of soil aridity	Small scale maps/global
Rozanov et al, 1981, 1982	Statistical information	Erosion, Salinization	Statistical tables at Global /regional level
Kharin et al, 1984	Satellite images and aerial photographs ground surveys	Status of vegetation, erosion, salinization	Medium scale maps statistics, regional scale
NRSA, 1990	Satellite imagery and ground truth studies	Degree of Soil erosion	Small scale maps/ regional level
NRSA, 1995	Satellite imagery and Ground truth studies	Degree/ extent of salinity and/or sodicity	Small scale maps/ National level
NRSA ,1996	Satellite imagery and Ground truth studies	Salinity/ sodicity	Medium Scale Regional level

The general approach for mapping and generating land degradation database will be as follows:

- Remote sensing multi-spectral data, preferably Resourcesat LISS-III or compatible resolutions, covering Kharif (Aug –Nov), Rabi (Jan- Mar), Zaid (April- May) seasons will be used to address spatial and temporal variability in land degradation. In the absence of cloud free data or quality affected data, the use of multisensor data may be contemplated.
- Development of classification scheme and interpretation cues for multi-temporal data sets.
- Georeferencing of multi temporal IRS LISS III datasets to standard spatial reference framework.
- On-screen visual interpretation of different land degradation classes on satellite data FCC following standard visual interpretation techniques adopting the finalized classification scheme and interpretation cues.

- Statistically sound sample points / grids will be identified for various land degradation classes from interpreted map for ground truth collection and for accuracy assessment.
- Field work has to be carried out by the interpreter including soil sample collection along with site details.
- During the field work the relationship between image elements and tentatively identified land degradation classes will be established that are delineated during preliminary interpretation. The sample points will be readjusted depending upon the variability in the field and sufficient points will be collected for finalisation of maps and accuracy assessment.
- The preliminarily interpreted land degradation map will be finalised in light of ground truth data and soil sample analysis (wherever done) to arrive at the final map. Existing legacy data on forests, wastelands, degraded lands, biodiversity, land use / land cover etc. canl be made use of for better delineation of land degradation classes.
- The minimum mapping polygon size of 3 mm x 3 mm on 1:50,000 scale equivalent to 2.25 ha area, would be followed while delineating the degraded lands from satellite data.
- Quality check has to be performed randomly and thematic maps are to be assessed for thematic as well as location accuracies.
- Digital geo-database would be developed to address retrieval and storage of different data inputs and outputs. Meta data elements have to be designed those area relevant to different types of input data.

The land degradation databases thus developed can be used along with various other thematic data sets like land cover, digital elevation model, climatic data sets for developing suitable reclamation plans.