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총 설

Satellite Remote Sensing for Forest Surveys and Management[1]

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ABSTRACT

The states of development of remote sensing, GIS and forest management technology are such that new directions in forest surveys and management are possible. The technologies can not be considered separately. With the increasing power and decreasing cost of computer processing and the development of inexpensive mass storage media, digital remote sensing applications are becoming more practical. Powerful microcomputer-based image analysis systems and GIS are important advancements. As well, it is only a matter of time before the integration of remote sensing image analysis systems and GIS becomes transparent to the users. Implementation of operational applications by both centralized agencies and local units is, therefore, becoming practical. This paper discussed the state of remote sensing technology and its application to forest surveys and management. The relative advantages and disadvantages of readily available remote sensing products for regional biodiversity assessment were summarized. Discussion is limited to the sources of up-to-date imagery suitable for regional land use/cover mapping, specifically : LANDSAT MSS and TM, and SPOT.

Key words : Forest surveys, classification, manual mapping, change detection.

要 約

遠隔探査, 地理情報시스템 및 山林經營技術의 發達과 함께 山林調査 및 經營에 있어서 新傾向이 擡頭되고 있다. 이러한 技術들은 서로간에 個別的인 것은 아니다. 컴퓨터의 資料處理能力이 增大되고 價格이 減少함으로 해서 數値遠隔探査는 보다 實質的으로 應用되어질 수가 있다. 이러한 發達로 畫像分析시스템 및 地理情報시스템 등은 마이크로컴퓨터를 利用하여 處理할 수 있게 되었다. 뿐만 아니라, 이러한 遠隔探査技術과 地理情報시스템은 漸次的으로 接木되어져, 中央機關 및 地方部署에서도 이를 利用한 實質的인 業務活用이 試圖되고 있다.

本稿에서는 遠隔探査技術의 現況과 山林調査 및 經營에의 應用에 관하여 考察하였다. 地域的 生物多樣性分析을 위해 可用한 遠隔探査資料에 대한 相對的 長短點을 要約하였으며, 土地利用 및 被覆圖作成에 適合한 랜샛 MSS와 TM 그리고 SPOT 등의 資料에 局限하여 考察하였다.

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INTRODUCTION

A large portion of the earth's renewable natural resources is made up of forests. All projections indicate that wood use will continue to increase because of the shrinking land base, increasing world population, and greater use of wood for energy and fuel. The forest manager must know where the natural resources occur and what their condition is in order to decide how best to balance the many demands on the resource for best utilization of future generations.

Remote sensing and image processing are powerful tools for many research and applications areas. Remote sensing may be defined as the process of deriving information by means of systems that are not in direct contact with the objects or phenomena of interest. Image processing specifically refers to manipulating the raw data produced by remote sensing systems. Remote sensing is a technology that has close ties to geographic information systems(GIS). For a variety of applications, remote sensing, while only one source of potential input to a GIS, can be valuable(Choung and Kim, 1992). It represents a powerful technology for providing input data for measurement, mapping, monitoring, and modeling within a GIS context. Indeed, it has been suggested that neither remote sensing of earth resources nor GIS can reach their full potential unless the two technologies are fundamentally linked(Estes, 1984). This is very likely the case as GIS, to be most useful, must have the up-to-date information that can often be extracted from remotely sensed data.

From a philosophical point of view, applications of remote sensing are fundamentally in the realm of GIS, since the same concerns, and the same overall processing flows, are found(Star and Estes, 1990). Seen this way, processing systems for remotely sensed data may, in large measure, be considered a specialized form of GIS. Remotely sensed data does, however, have certain unusual features, which may necessitate special-purpose components in the system. Furthermore, digital remote sensing systems often create immense volumes of raster data, which may stretch current computer processing and storage systems to their limits(Choung, 1993). Overall, however, we view a GIS as a generic system for manipulating spatial data, and see remote sensing and image processing as more specialized techniques of such systems.

In this scheme of best use, remote sensing plays a key role to assist in making accurate, timely and cost effective resource evaluations(Heller and Ulliman, 1983). Foresters were among the first to use remote sensing data for applications to inventory, damage assessment, management and recreation. The objective of this paper is to make GIS users more aware of the wide range of information that can be produced using satellite remote sensing technology and applied to forest surveys and management. For an introduction to the principles and theory of remote sensing, the reader is referred to *Manual of Remote Sensing*(Colwell, 1983), and to the texts by Richards(1986) and Elachi(1987).

METHODS

Basic Principles

Remote sensing systems range from active sensors that measure how a signal is scattered by the surface to passive systems that measure surface reflectance or emission(Scott et al., 1990). The basic properties of a remote sensor can be summarized as :

-spectral coverage(band width location) ;
-spectral resolution(spectral band width) ;
-spectral dimensionality(number of bands) ;
-radiometric resolution(quantization) ;
-instantaneous field of view(IFOV) ;
-point spread function.

The spatial resolution of a sensor is often equated with its IFOV, but resolution also varies with other factors such as atmospheric properties, scene characteristics, and data preprocessing. A more practical measure of resolution is the *effective resolution element*, which is the minimum sized object that can be detected against a spectrally contrasting background. Simonett et al. (1983) suggest that the effective resolution required for identification of an object may be three times smaller than the effective resolution for its detection.

The repeat interval of a sensor system is determined by satellite platform altitude, angular velocity, orbital inclination with respect to the equator, and orbital orientation with respect to the vernal equinox. The LANDSAT satellite is placed in a sun-synchronous near polar orbit to achieve global coverage and consistent illumination geometry, with an overpass time near 09 : 30 AM and a sixteen day repeat cycle. SPOT is also placed in a near-polar sun-synchronous orbit, and has a 10 : 30 AM overpass with a repeat cycle of three days. The pointing capability of this sensor means that off-nadir data can be acquired more frequently.

Table 1 lists some of the basic features of a number of operational and planned satellite-borne sensors that can provide information on land use/cover. LANDSAT Multispectral Scanner(MSS) and Thematic Mapper(TM), and SystèmePour l'Observation de la Terre(SPOT) are all well suited to mapping land use/cover and provide full coverage of the Korean Peninsula. Additional detail on these sensors is provided in Table 2. The cost of digital satellite data has increased dramatically since the commercialization of the LANDSAT program in 1980, and may be a deciding factor in the choice of data source and form. For this reason, I also included the costs of the different data products as of July 1, 1993.

Considerations in Choice of Sensor and Data Products

Recent LANDSAT MSS and TM data have already been collected for most of the Korean Peninsula and are readily obtained from the Chang Woo, Incorporated of Korea or the Remote Sensing Technology Center(RESTEC) of Japan in a variety of formats. TM has several important advantages over MSS(Scott et al., 1990), specifically :

- higher signal-to-noise ratio ;
- greater quantization(higher precision of radiometric data) ;
- greater cartographic accuracy ;
- higher spectral dimensionality(particularly mid-infrared bands).

Although the higher spatial resolution of TM data may be important in mapping some features such as wetlands or urban areas, it can actually produce lower classification accuracies for many vegetation types that are spectrally heterogeneous at this sampling resolution(open woodlands and shrublands are especially problematic). An obvious drawback to using TM is the four-fold increase in cost relative to MSS. Furthermore, the higher resolution of TM data imposes a seven-fold increase in data volume per band(Table 1). The advantages cited above, however, make TM data far superior to MSS data for digital or manual land use/cover mapping.

The French-owned SPOT sensor has been operating since February 21, 1986. Data acquisition can be ordered for any location in the Korean Peninsula. The SPOT High-Resolution Visible(HRV) sensor has several assets that make it attractive for biodiversity analysis(Scott et al., 1990), including :

- contemporary acquisition ;
- high cartographic quality ;
- high radiometric resolution ;
- late-morning acquisition(reduces shadowing) ;
- multiple viewing angles for better temporal coverage.

Table 1. Characteristics of Operational Sensors Currently Used to Map Regional Land Use and Vegetation Cover.

Platform	Sensor	Date	# Bands	Spectral	Resolution	Repeat
LANDSAT	MSS	1972	4	VIS/NIR	80m	18 days
	TM-4, 5	1982	7	VIS/NIR/TIR	30/30/120	16 days
	TM-6	1993	8	VIS/NIR/TIR	20/30/120	16 days
NOAA	AVHRR	1978	5	VIS/NIR/TIR	1 to 4km	12 hrs
SPOT	HRV-P	1986	1	VIS	10m	3 days
	HRV-XS	1986	3	VIS/NIR	20m	3 days

VIS-Visible ; NIR-Near Infrared ; TIR-Thermal Infrared ; NOAA-National Oceanic and Atmospheric Administration ; AVHRR-Advanced Very High Resolution Radiometer ; P-Panchromatic ; XS-Multispectral.

Despite some advantages, digital SPOT data are probably less suited to mapping natural vegetation than TM data because of their lower spectral dimensionality(most importantly, SPOT lacks mid-infrared bands). The higher spatial resolution of SPOT data makes them very useful for analyzing localized environments such as wetlands and urban areas, but produces even more unwanted disaggregation of some vegetation types compared with that of TM data. Also, on a per area basis, digital SPOT data are considerably more expensive than TM data.

SPOT film products have been shown to be useful for manual mapping of natural vegetation, and should be considered as an alternative source when TM data are unavailable. Using the standard band combination for false color composites of green, red and near-infrared, SPOT and TM standard film products will probably yield similar results. Some added precision and detail can be obtained from SPOT data, but at considerably higher cost(Table 2). In a comparison of film products for mapping forest and agricultural cover types, DeGloria and Benson(1987) obtained the highest accuracies using false color composites developed from red, near-infrared and mid-infrared channels. This suggests that the best results from manual mapping may be

Table 2. Data Characteristics of LANDSAT MSS and TM, and SPOT Sensors. Prices are as of July 1, 1993 and are represented in U.S. dollars. Digital data prices are for non-geocoded products.

LANDSAT MSS		
	Spectral response(microns) : Band 1	0.5-0.6
	2	0.6-0.7
	3	0.7-0.8
	4	0.8-1.1
	Scene size : 185 by 170km	
	Pixel quantization : 4 bit(0-63)	
	Data cost : Digital scene	$1,000
	1 : 1,000,000 film transparency	$600
	1 : 1,000,000 print	$550
	1 : 500,000 print	$700
	1 : 250,000 print	$1,000
LANDSAT TM		
	Spectral response(microns) : Band 1	0.45-0.52
	2	0.52-0.60
	3	0.63-0.69
	4	0.76-0.90
	5	1.55-1.75
	6	10.40-12.50
	7	2.08-2.35
	Scene size : 185 by 170km(1 quadrant is 100 by 100km)	
	Pixel quantization : 8 bit(0-255)	
	Data cost : Digital scene	$4,400
	Digital quadrant	$3,100
	1 : 1,000,000 transparency	$2,700
SPOT HRV		
	Spectral response(microns) : Band 1	0.50-0.59
	2	0.61-0.68
	3	0.79-0.89
	Scene size : 60 by 60km	
	Pixel quantization : 8 bit(0-255)	
	Data cost : Digital scene	$2,450
	1 : 400,000 film	$1,800
	1 : 200,000 film	$1,800

obtained using non-standard TM products.

Satellite Imagery and Computer Processing

Satellite data are available in photographic form, either as black and white images or as false color composites at scales of 1 : 1,000,000 through 1 : 50,000(Choung, 1992). Satellite data in digital form are available as computer compatible tapes(CCTs). The data, whether in visual or digital form, provide a synoptic view of very large areas under uniform illumination conditions. The repetitive coverage provided by the system offers the possibility of obtaining data from large areas at different dates or seasons. Subject to cloud cover limitations, the selection of imagery from optimal periods for land cover analysis can be achieved.

Satellite data can be interpreted using variously combined-band images(usually TM bands 1, 2 and 3 for a true-color composite, and 2, 3 and 4 for a false-color composite), or using single-band black and white images. Satellite imagery is essentially free of relief displacement, so that the process of transferring the boundaries of thematic classes from an image to a base map is relatively straightforward (Singh, 1986). Considerable information can be derived from satellite data in photographic format. However, the major advantage of the satellite imagery is that it generates digital numbers on magnetic tape which are amenable to computer-assisted analysis(Lillesand and Kiefer, 1987). Consequently, since the launch of the LANDSAT series of satellites in 1972, there has been a progressive shift from conventional photo-interpretative procedures to computer-aided analysis. This has been stimulated by parallel developments in digital image processing systems, which once appeared to be the rich man's pastime (Townshend and Justice, 1981). In general, digital image processing systems require various input/output devices together with system consoles for man-machine interaction. Each image processing task usually involves relatively simple, but highly repetitive operations on vast amounts of image data(Ince, 1983).

Initially, digital image analysis was undertaken using large, mainframe computers and operated solely in batch mode. The second generation of data processing systems for remote sensing was also designed for large, mainframe computers, but took advantage of interactive demand mode processing. The third generation of systems was developed for minicomputers and specifically designed to speed up certain algorithms, with a consequent improvement in the interactive capabilities of the systems. In general, mainframe systems and dedicated image processing systems are prohibitively expensive for the majority of remote sensing centers in developing countries(Singh, 1986).

In recent years, as a result of the revolution in microchip technology, computers and their peripherals have become much cheaper, and microprocessor-based systems are being developed that allow interactive analysis of digital data at much lower price. With interest increasing in the use of microcomputers for image processing, software systems are now becoming commercially available. Microcomputer-based systems of this kind are most suitable for applications in developing countries(Singh, 1986).

Digital Image Classification

Image classification is generally accomplished by cluster analysis, which is often referred to in the literature on remote sensing as *unsupervised classification*, or by discriminant analysis or pattern recognition techniques, referred to as *supervised classification*. I will not attempt to review this enormous literature, but refer the reader to the work by Richards(1986).

Unsupervised classification involves clustering individual pixels into spectral classes based on measured reflectance values in the original channels or transforms of those channels. The spectral classes are then assigned to land use/cover classes by an analyst based on other information such as field observations, aerial photographs, and existing maps. Papers by Strahler(1981) and Franklin et al. (1986) describe an unsupervised approach to mapping forest vegetation that has been highly successful. The general steps that are followed in their procedure are shown in Figure 1.

In supervised classification, pixels are assigned to land use/cover classes through a discriminant func-

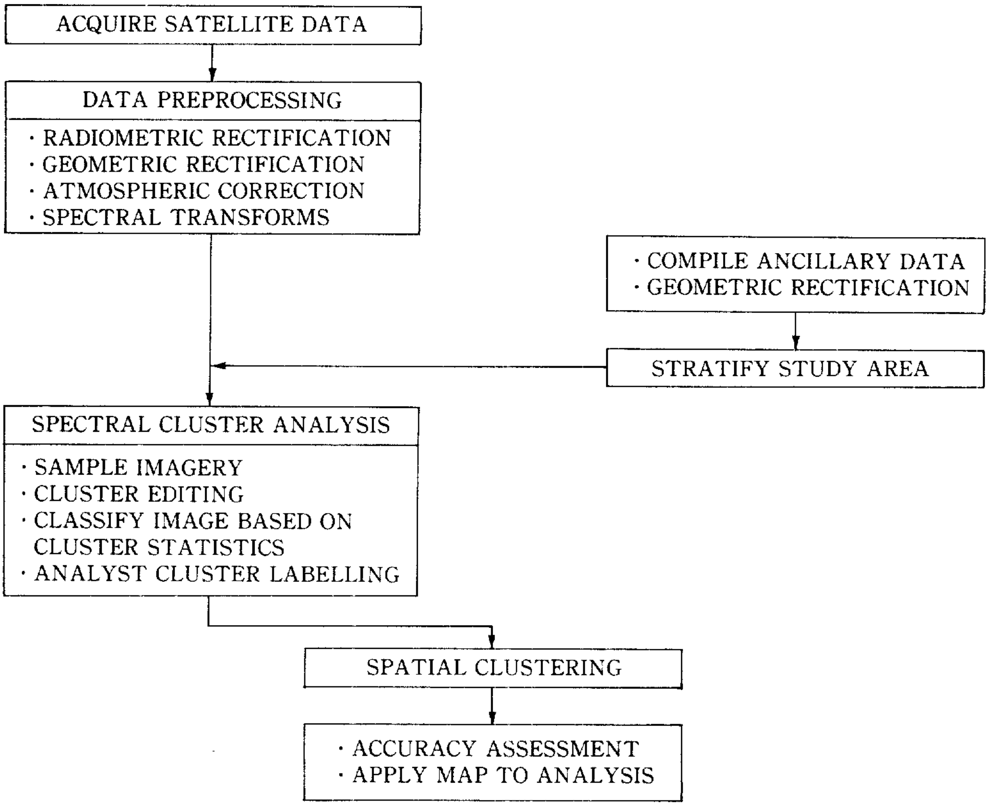

Fig. 1. Flow Chart Showing Steps Taken in Unsupervised Classification of Digital Satellite Data Using the FOCIS Method Described by Franklin et al. (1986).

tion based on spectral properties of those classes in a set of pre-selected training sites. Several different methods of supervised classification have proven successful for mapping urban and agricultural features. These methods have not been as successful in mapping natural vegetation because of the spectral heterogeneity of the classes, which makes it difficult to specify an adequate set of training sites.

Hybrid approaches also exist that combine supervised and unsupervised methods, using unsupervised classification to generate training classes that are subsequently used in a supervised classification procedure. Another hybrid approach is the guided clustering, which involves initial seeding of spectral clusters or pooling of clusters based on training statistics.

The success of image classification depends on whether land use/cover classes possess distinctive spectral signatures (Scott et al., 1990). Atmospheric effects corrections and band transforms often improve class separability. For example, band ratios such as the Normalized Difference Vegetation Index (NDVI) have proven effective in removing unwanted spectral variation due to topography. High classification accuracies may also depend on incorporating ancillary cartographic information in order to segment the image into regions that are physically or spectrally more homogeneous. For example, digital elevation data have been used to account for illumination effects and to stratify a scene into ecological zones. Similarly, maps of soils, geology or general land use/cover patterns can be very effective in segmenting imagery to improve the relationship between spectral classes and land use/cover classes.

All of the digital image classification techniques just described depend on having accurate up-to-date ground information, recent aerial photography, and ancillary cartographic information for cluster labelling, training class selection, image segmentation, or inclusion of prior information.

Manual Interpretation of Satellite Imagery

Manual interpretation of satellite imagery entails the drafting of polygons onto the printed image products(typically false color composites) (Scott et al., 1990). The process is much the same as photointerpretation of aerial photography in that the analyst relies on perceived differences in image tone, texture, and context to delineate polygons. The main differences are the much lower effective resolution of satellite imagery compared to that of aerial photographs and the lack of stereo-viewing. Many of the features used by photointerpreters to identify land use/cover types, such as canopy spacing and height, building shape and arrangement, hillslope form, and so forth, are not discernible in satellite imagery. This means that while polygon boundaries can often be placed with high accuracy, polygon labelling generally requires analysis of recent aerial photographs or reliable land use/cover maps.

A number of methods have been used to manually produce land use/cover maps using satellite data. Scott et al. (1990) described how satellite data were photointerpreted in Idaho, U.S.A., to update a state-wide vegetation map that was prepared by compressing existing land use/cover maps. Others have used satellite imagery as the primary source of information. Davis et al. (1990), for example, used 1 : 250,000 scale TM images to map land use/cover over six million acres of southern California. Polygons were drafted onto clear mylar overlays and then digitized using the ARC/INFO GIS software system. Polygons were labelled by enlarging the mylar overlay to the scale of recent photography from the National High Altitude Photography (NHAP) program, overlaying the polygons on the photographs and labelling them by photointerpretation using a stereo viewer. Vegetation boundaries that were mapped incorrectly on the satellite image were edited at that time and incorporated into the final digital map. The procedure is diagrammed in

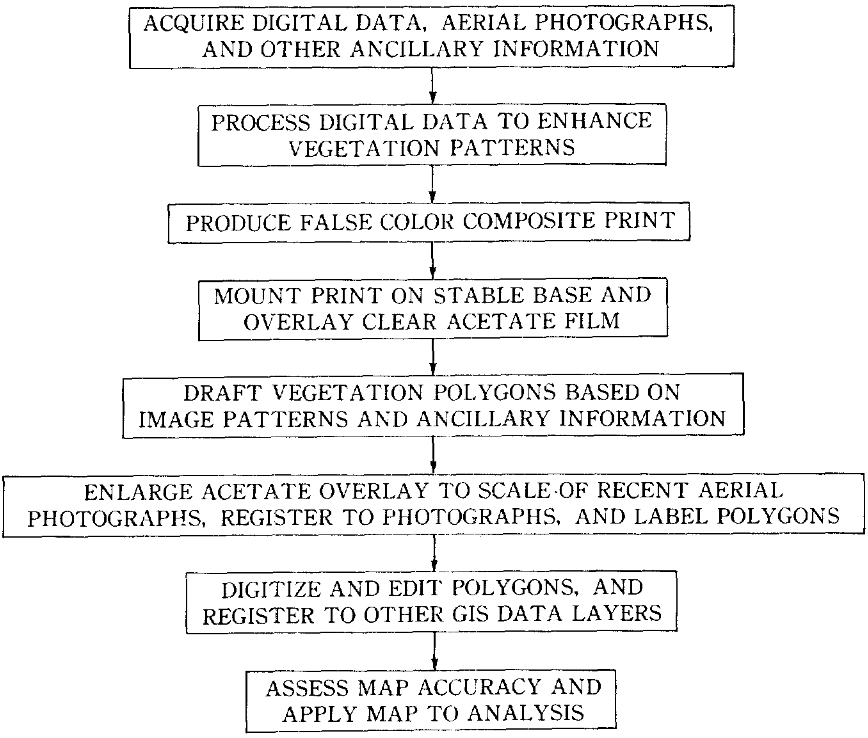

Fig. 2. Flow Chart Showing Steps Taken in Manual Vegetation Mapping Using TM Prints.

Figure 2.

Within the forests of the western Cascades and Coast Range of Oregon, it was possible to identify several major features of the ecological landscape based on structural criteria identified by visual inspection of false color paper prints of recent LANDSAT MSS imagery (Scott et al., 1990). These included pre-settlement forests, second-growth forests dominated by evergreen conifers or deciduous trees, and several structural patterns correlated with various silvicultural practices. The boundaries between these units were drawn directly onto drafting film overlaying the images.

Most manual mapping with satellite data is performed using standard film products that have already been radiometrically and geometrically rectified. These products are not optimally suited to mapping heterogenous natural vegetation, especially in the areas of high relief. Problems such as terrain shadowing and poor spectral separation of cover types can often be overcome using the appropriate ratios, image segmentation, and density slicing techniques. This requires the purchase of digital data and depends on the facilities for producing high-quality film or paper output.

Comparison of Digital versus Manual Mapping

Digital and manual mapping will yield fundamentally different models of habitat distributions. Most importantly, digital classification operates on a per pixel basis, whereas manual interpretation involves subjectively delineating the boundaries of land cover entities that tend to be many pixels in size. Whereas the spatial detail of a digital product will be limited by image resolution, that of a manual product is limited by the minimum mapping unit that can be drafted, and by the analyst's perception of the appropriate size and level of generalization for the map information classes, given the purposes to which the map will be applied.

Vegetation and habitat types are human abstractions that possess spatial features such as pattern, size, and shape. These properties are not easily recovered from digital satellite data. There are procedures that use local spatial information, image segmentation or expert systems approaches to generate more object-like image classes (Wharton, 1989 ; Bryant, 1990), but these can be quite complex and software for such procedures is not widely available. Manual interpretation often results in map units that are better suited to land management applications where the units of classification are broad and physically heterogeneous (for example, a photointerpreter may have no difficulty delineating residential areas on a photograph, but the same area might be disaggregated by digital classification into several spectral classes corresponding to lawns, houses, trees, etc.). On the other hand, manual photointerpretation involves a good deal of generalization and loss of spatial detail that is retained in digital classification.

The general advantages and disadvantages of digital image classification for habitat mapping can be summarized as follows :

Advantages-

- -spatial detail ;
- -consistency of representation over large areas ;
- -ease of multi-temporal analysis and map update ;
- -potentially high classification accuracies ;
- -flexibility in representing different levels of spatial detail through aggregation or disaggregation ;

Disadvantages-

- -higher data cost ;
- -higher data volume (not always true) ;
- -requires trained technicians and specialized hardware and software ;
- -difficult to convert the raster product to vector format without considerable data aggregation, and loss of accuracy and detail ;
- -higher production costs.

The advantages and disadvantages of manual mapping are :

Advantages-

- -object oriented approach yields large polygons that may conform better to the habitat classification system and cost less for data storage and analysis ;
- -lower production costs ;
- -requires less personnel training and technology ;

Disadvantages-

-less spatial detail than digital classification ;
-photointerpretation errors in boundary placement and digitizing ;
-requires synoptic coverage by ground truth information ;
-generalization of habitats eliminates the potential use of spatial diversity indices(e.g., local complexity and ecotones).

Forest Type Mapping

Satellite data have shown a good capability for mapping broad forest types, but are not appropriate for acquiring detailed information suitable for management inventories. Enhancements of LANDSAT MSS data have been used effectively for mapping forest fire fuel types(Kourtz and Scott, 1978). Johnson et al.(1979) and Bryant et al.(1980) showed classification capabilities for classes such as hardwoods, softwoods, several classes of mixed woods, open wetlands, and clear-cuts. Classifications have been used to generate a fuel type data base for a decision support system for forest fire prediction and fire growth modelling(Kourtz, 1984) and have aided forest site type mapping for taxation purposes in Finland(Häme, 1984). Inventory techniques based on multistage or multiphase sampling techniques have been developed using the capabilities of LANDSAT MSS to classify broad forest types(Titus et al., 1975). Some conifer species discrimination capabilities have been observed and reported for LANDSAT MSS data(Mayer and Fox, 1981), but consistent discrimination has not been possible.

Improved forest mapping capabilities are available with LANDSAT TM owing to the added spectral bands and spatial resolution, and with SPOT owing to higher spatial resolution(Leckie, 1990). Improved radiometric sensitivity of both sensors over LANDSAT MSS also aids in forest mapping. The higher spatial resolution is definitely beneficial for visual interpretation. The imagery can almost be interpreted at the stand level. In some cases the increased resolution can cause the accuracy of automated classification procedures to be poorer(Markham and Townshend, 1981). At higher resolutions forest stands often look less homogeneous as the areas of varying species mixtures or crown closure become distinct units. This causes greater variance in the reflectance from a forest stand and difficulties in classifying forest type. Some improved species separation is possible with LANDSAT TM(Shen et al., 1985 ; Franklin, 1986), but again, consistent species determination is not possible. Both SPOT and LANDSAT TM do, however, in general, provide improved capabilities for forest mapping(Teillet et al., 1981 ; Jaakkola et al., 1984 ; Nelson et al., 1984 ; Buchheim et al., 1985 ; Ahern and Archibald, 1986) and have an important role in broad forest type mapping. They can also be helpful in defining patterns of forest type(e.g., old-burn areas), which is useful supplemental information for more detailed forest mapping by other remote sensing methods.

Inventory Update

One of the most important applications of digital remote sensing data obtained from earth-orbiting satellites is the recording of land use/cover changes through time, because of repetitive coverage at short intervals and consistent image quality(Anderson, 1977 ; Nelson, 1983 ; Singh, 1989). Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times(Singh, 1989). Essentially, it involves the ability to quantify temporal effects using multitemporal data sets(Choung et al., 1994a).

Various procedures have been proposed and used to detect changes in land use/cover using satellite imagery. These remotely sensed data are particularly suitable for land-use/cover change detection because of their timeliness, synoptic view, repetitive coverage, and flexibility of data analysis(LeDrew et al., 1987). The fundamental assumption in using remote sensing data for change detection is that any changes in land cover will result in changes in spectral values which are sufficiently large with respect to digital changes caused by other variables (Choung, 1992). These 'other' variables, frequently resulting in change-detection error, include differences in atmospheric conditions, differences in sun angle, and differences in soil moisture(Jensen, 1983 ; Milne, 1988). If these variables are well-controlled, it may be possible to analyze the spatial, spectral, and temporal characteristics of the remodely sensed data to obtain land-use/cover change statistics and produce a land-use/cover change map.

For change detection, both photographic and digital methods can be employed. It is suggested that a digital rather than a photographic or visual approach be used in the analysis(Howarth and Wickware, 1981). A visual approach allows for easier data analysis and extraction of information, and may be appropriate at a very general level of resource management decision making. It may allow the investigator to stratify the area and identify locations for more detailed digital analysis and field investigation. In visual analysis, however, the resolution of the image and hence the level of detail that can be observed are less than can be achieved with digital analysis.

The principal techniques of digital change detection techniques are outlined in the following way.

Most digital change detection procedures require the atmospheric effects correction and the accurate spatial registration of satellite images from different dates(Choung et al., 1994b). A residual image is produced by various procedures, and then a threshold value, determined empirically or statistically, is applied in order to separate areas of change from those of no-change. These change detection methods are categorized as enhancement techniques and are relatively simple, economic and computationally fast(LeDrew et al., 1987). They can not, however, be used to identify the nature of change or generate statistics about the change. Another available technique involves the independent classification and subsequent comparison of images from different dates. The classification technique can be used to identify the nature of change, but the success of this approach is often plagued by the combined effect of errors in the classification of individual scenes (Choung et al., 1994b). These errors could be considerable in the analysis of areas with high frequency land-use/cover patterns.

CONCLUSION

This paper has provided an introduction to remote sensing principles and techniques for forest surveys and management. Human image interpretation is a powerful tool, especially when aided by image analysis techniques and easy access to other existing knowledge about a site. Automated interpretation is advantageous, as it is more objective than human interpretation and relieves the interpreter from examining a vast detail of data and incorporating diverse information. Development of new automated methods is necessary. The most important consequence of advances in satellite sensor technology will be in improved capabilities to monitor the forest.

Remote sensing has been a critical technology in forest surveys and management. With the changing technological infrastructure in forestry, the increasing complexity and importance of forest management decisions, a growing demand for more forest resource information, and rapidly developing remote sensing technology, remote sensing will be increasingly effective in improving forest management.

Remote sensing and GIS technology developed separately. In part this was a result of the use of different types of equipment and the need for different technical skills. While a user of remote sensing technology may develop expertise in sensor systems and image processing methods, the expert GIS user may become more familiar with principles of map projections, spatial analysis, and the design of spatial data bases. Although the technology may encourage different technical orientations, in both cases the user must understand the nature of the information being collected-the forestry, geology, building structures, roadway design, and so on.

Ultimately, remote sensing and GIS technology are both used to collect, analyze, and report information about the earth's resources and the infrastructure we have developed to use them. The two technologies provide complementary capabilities. Remote sensing analyses are improved by the verification data retrieved from a GIS, and GIS applications can benefit from the information that remote sensing can generate. Often the image data are the most current spatial information available for an area. The use of digital image data offers the additional advantages of a computer compatible format that can be input directly to a GIS.

The integrated use of remote sensing and GIS methods and technology can not only improve the quality of geographic information but also enable information previously unavailable to be economically produced. Over the past few years manufacturers have developed more sophisticated technology for integrating remote sensing systems and geographic information systems. The effective use of these tools, however, depends on users sufficiently knowledgeable to apply them.

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