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**A FEASIBILITY STUDY OF INTEGRATING REMOTE
SENSING INTO THE ELECTRONIC ATLAS OF CANADA
BASED ON THE IDRISI SYSTEM**

By Shabai Huang

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of**

Master of Arts

Department of Geography

Carleton University

Ottawa, Ontario

January 5, 1992

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SENSING INTO THE ELECTRONIC ATLAS OF CANADA
BASED ON THE IDRISI SYSTEM**

**submitted by Shabai Huang
in partial fulfillment of the requirements for
the degree of Master of Arts**

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Thesis Supervisor

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January 5, 1992

ABSTRACT

The research deals with the integration of remotely sensed data into the Electronic Atlas of Canada (EA). It aims to provide national mapping with more efficient data acquisition methods and more realistic methodologies for spatial data representation.

Analyses of the basic characteristics of remotely sensed data and its potentials for national atlas mapping and of the potential approaches to the integration of remote sensing into the EA system were conducted. A system integration of the EA with the IDRISI, a geographical information analysis system, has been achieved based on a loose coupling concept and the system functionalities of both the EA and the IDRISI systems in the integration were defined. In addition, procedures for the thematic information extraction from the remote sensing data, a set of image post-processing procedures, and a set of image mapping procedures were developed. Finally, experiments in image classification, image post-processing, image mapping, polygon data transfer from IDRISI to EA and vice versa were carried out in order to test the functionality of the integration.

The results show that the integration, based on the selected integration approach, and the functionalities of image classification, image post-processing and the image mapping are feasible for the national mapping program.

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CHAPTER 1

INTRODUCTION

1.1 THE INITIATIVE OF THE RESEARCH

Geographic Information Systems (GIS) have been developed from the need to combine attribute information about land with its cartographic representation in order to perform spatial analysis. GIS technology provides researchers, resource managers, and decision makers with a tool for effective storage and manipulation of remotely sensed data and other spatial and non-spatial data. As such, GIS can be used to facilitate measurement, mapping, monitoring, and modelling of a variety of data types for both scientific and commercial applications. Space remote sensing and image processing technologies have been used in parallel to obtain information about the earth at resolutions ranging from tens of centimeters to planetary scales. They provide researchers, resource managers, and policy making personnel with powerful tools for producing spatial and temporal information. Thus, GIS and remote sensing technologies are demonstrably powerful tools for the management, collection, analysis, and classification of spatial data.

However, due to technical and institutional reasons, these two technologies have been developed in parallel over the past two to three decades. Experiences, gained in the technical developments of GIS, in the remote sensing domains, and in the increasing requirements of application domains, have clearly illustrated that the further development of these technologies and their applications can only be achieved through the integration of the two technologies (Lauer et al., 1991). The major advantages of the integration of these two powerful technologies are the synergism between remotely sensed data for updating GIS

information, and the use of GIS for improving the information extraction potential of multi-sensor data.

The Electronic Atlas of Canada (EA), developed at the Geographical Services Division (GSD), Energy, Mines and Resources (EMR) Canada, is a GIS-like spatial information system, which emphasizes cartographic functionality, and intends to contain a large set of authoritative national thematic maps (Siekierska and Taylor, 1991). Because of the advantages of the integration of remote sensing into GIS, a program was initiated in the GSD to integrate remote sensing technology into the EA system. This research project is part of this program.

1.2 OBJECTIVES OF THIS RESEARCH

This research attempts to conduct a feasibility study of introducing remote sensing into the electronic mapping of the EA system. It emphasizes on the study of possible integration methodologies for the specific integration task, the development of operational procedures for all subtasks related to the project, and the construction of an experimental integrated environment to demonstrate the feasibility of the methodologies and procedures developed. The IDRISI system is used as an image processing supporting system for this research, since it is the only system available in GSD that provides basic image processing capabilities. Within the constructed experimental environment, users will be able to incorporate remotely sensed data into EA displays and into the national atlas mapping applications. In order to achieve this goal, the following specific efforts are needed:

- (1) *Analyzing the potential utilization of remotely sensed data for the national atlas mapping program.* This analysis is an attempt to provide the integration with a guideline to more

efficiently introduce remotely sensed data to the national atlas mapping program of Canada.

(2) *Analyzing the strengths and weaknesses of the IDRISI system as a support system for image processing in the integration.* The EA system is a GIS-like cartographic system which emphasizes cartographic functionalities. It does not provide basic functionalities for remotely sensed processing which is crucial for introducing remote sensing into the EA system. Thus, a supportive system is needed to carry out relevant processing. The IDRISI system is to be tested for this purpose.

(3) *Investigating possible avenues for the integration.* A number of research approaches has been found in the integration of remote sensing into GIS (Derenyi and Pollock, 1990; Zhou, 1989; Lillesand et al., 1989; Logan, 1987). For instance, Zhou (1989) conducted research on developing an operational image-based GIS which incorporates a GIS (the ARC/INFO system) and an image analysis system (the DIPIX ARIES II) and effectively used the system for land resource studies in the arid zone of Australia. These provide good references for the integration studies. Nevertheless, the situations vary with software and hardware environment and with application domains. It is therefore necessary to examine the advantages and disadvantages of various integration possibilities, in order to find a solution that best suits the current task.

(4) *Implementing the integration of the EA and the IDRISI systems.* Based on the analysis of various integration avenues, an appropriate approach will be developed that can optimally integrate the IDRISI system and the EA system. There are fundamental differences in operations of spatial analysis and spatial data management between these two systems. The efficient integration of these two systems relies on appropriate

utilizations of the capabilities of each system, and on the proper design of data interchange between the two systems.

(5) *Developing practical procedures of thematic information extraction for national atlas mapping.* Extraction of thematic information for national atlas mapping is one of the most important tasks in the integration, since, in most cases, only certain thematic information is required for national thematic mapping. Practical procedures for the extraction of thematic information need to be developed, in order to provide a norm for later integration operations.

(6) *Establishing mechanisms for image post-processing.* There is an apparent gap in the integration of remote sensing and GIS. GIS specialists regard accurate, digital point, line and polygonal data as the raw data for GIS applications, whereas to remote sensing specialists, the classified remotely sensed data sets, expressed in raster or vector format, are considered as highly processed products. The difference in the viewpoint between specialists in the GIS and remote sensing domains results in a gap, which must be resolved in the integration. The implementation of image post-processing mechanisms is a solution for this problem. The related mechanisms aim to take the responsibility of conducting post-processing operation on classified remote sensing images in order to provide qualified spatial data for GIS applications regarding GIS data requirements.

(7) *Developing procedures for national coverage temporal and atemporal image mapping.*

Remote sensing technology provides several advantages in spatial information representation over the traditional cartographic techniques. For instance, it can provide users with more realistic representation of spatial information for national mapping applications. Users can efficiently create two-dimensional and three-dimensional image

maps with remote sensing technology. Also, the technology can efficiently provide national atlas mapping with temporal national coverage spatial data, which can be used for map revision or dynamic environment monitoring. Thus, a series of procedures for generating a variety of image maps need to be developed, in order to provide the EA system with image mapping capabilities.

1.3 SIGNIFICANCE OF THE INTEGRATION

1.3.1 Benefits of the Integration to GIS and Remote Sensing

The benefits of integration to the development of both GIS and remote sensing can be examined from two aspects: the application aspect and the academic aspect.

Application Aspect

From the viewpoint of applications, the integration can considerably benefit both GIS and remote sensing in map production, map revision, topographic data generation, terrain visualization, change detection, spatial and dynamic modelling in GIS, and image segmentation in image processing.

Map production Remotely sensed data, especially from Landsat TM and SPOT HRV, has been shown to be suitable for base map production at scales 1:50 000, which were previously considered impossible for remote sensing applications (Rose et al.,1986; Dowman, 1987; Gudan et al.,1988). This potential of remotely sensed data can certainly meet the scale requirements of national atlas mapping (1:2 millions and 1:7.5 millions). It promises greater reliability, i.e. lower "meta-uncertainty" (uncertainty about uncertainty) for map production than traditional data capture approaches, since map errors are known

and can be tracked throughout the map generation process. Traditionally, digitized maps contain errors which are often hidden or simply unknown.

Map revision The revision or updating of spatial information in a GIS is a time-consuming task. With remote sensing images, as well as the integrated analytical mechanisms of remote sensing and GIS, the efficiency of accomplishing this task can be considerably enhanced. Examples include Goodenough et al. (1987) who used remotely sensed data to update the forest maps of British Columbia of Canada.

Digital elevation model (DEM) generation This is one of the successful areas of integration (Huang and Zhang, 1991a; Simard et al., 1988; Ehlers et al., 1990). The accuracy presently achieved by using remotely sensed data allows the generation of DEM and ortho-images at scales of 1:50 000, from which further topographic information for GIS applications can be derived.

Terrain visualization Another application of the integration from which users can benefit is terrain visualization. Remotely sensed images, combined with a DEM of areas of interest, can be used to produce realistic perspective views of the ground which can be utilized for planning and environmental impact analysis (Starr, 1990; Gimblett, 1989; Turner, 1988).

Change detection An application in which considerable integration gains have been achieved is that of change detection, e.g., detecting changes in forest distribution, snow coverage, urban growth, etc. Remote sensing offers a greatly enhanced capability in updating thematic information for GIS on a regular base. Ehlers et al. (1990) demonstrated that SPOT data could be used in a GIS environment for regional growth analysis and local planning at a scale of 1:24,000. It was shown that SPOT image data yield accuracies for growth detection as high as 93 percent; once the data are incorporated into a GIS, the

spatial growth pattern can be readily analyzed (Ehlers et al., 1990; Thacher, 1987; Gwynne, 1986). Achard and Blasco (1990) effectively used NOAA AVHRR data to monitor vegetation phenolic cycle, to assess deforestation processes and to map forest cover in West Africa.

Aid in remotely sensed analysis The reverse data flow, from a GIS to the remote sensing system, is highly desirable, since substantial improvements can be made in classification accuracy if ancillary data (such as terrain, soil, previously determined land cover, etc.) is used in the classification process of remote sensing (Ait Belaid et al., 1989; Edward, 1989). Ait Belaid experimented with the integration of cartographic data with multi-spectral image data (SPOT, MSS) as a guide to conducting image segmentation over an agricultural site containing very small plots of land. The result was highly successful, since it achieved classification accuracies and surface area accuracies on the order of 90 percent. Using information already available in a GIS to improve the classification scheme will, in turn, make the remote sensing inputs more usable by the GIS.

Spatial modelling The importance of spatial modelling in GISs is increasing. The use of GIS for simple two-dimensional modelling using standard overlay procedures is now widespread. However, extension to three-dimensional spatial and dynamic modelling is crucial for applications in such disciplines as climatology, geology, soil studies (Davis and Davis, 1988; Burrough et al., 1988). Remote sensing could be an appropriate data source for this purpose.

Academic Aspect

The integration, from the academic standpoint, can be beneficial in remotely sensed data management and in creating a new data source for GIS.

Remotely sensed data management New detectors and imaging technologies are increasing the capabilities of remote sensors in the acquisition of digital spatial information at very fine resolutions. The management of data from existing space platforms, such as Landsat or SPOT, already taxes the management capabilities of organizations which need these data. With the advance of space programs such as the Earth Observing System (EOS), this problem is going to become even greater. The management of such information is going to be one of the major challenges of the coming decades. The means for overcoming these problems exist in the form of GIS technology (Estes, 1985; Ehlers et al., 1989; Campbell and Cromp, 1990), but the technology must be adapted, modified, and extended if it is to serve the needs of managing this kind of information. The integration of remote sensing and GIS technologies is an important step in the resolution of these problems.

New data source for GIS Nearly all of the currently operational geographic information systems, including the Electronic Atlas of Canada, utilize maps as their primary source of spatial data. The complex documents, designed for visual search and retrieval by human operators, are digitized (usually manually) and then entered into the master spatial data base of GIS. Although many of the maps used as input are derived from air photography or other remote sensing devices, there is little use of digital remote sensing data, especially data obtained from orbital platforms, as a direct data input. This approach makes it impossible to provide up-to-date data for dynamic monitoring of geographic phenomena, such as environment and forest resources, since the production of traditional maps is time consuming. Also, the many procedures involved in map production increase the errors found in the databases. These drawbacks inevitably restrict the potential applications of GIS. In the last few years, remote sensing images have been shown to be a natural and cost effective means for updating GIS databases, and have increasingly been used as direct data inputs to GIS (Ehlers et al., 1989), though substantial improvements in these attempts

have to be made, such as the improvement in image classification accuracy, etc. The integration of remote sensing with GIS is a significantly important effort in this direction.

1.3.2 Benefits of the Integration to the National Atlas Mapping

The national atlas mapping program can also substantially benefit from the integration. Space remote sensing, together with image processing technology, can provide the National Atlas Information Service with an efficient and effective data source, and, also, with data representation methodology. The domains which may benefit include: map production, map revision, DEM generation, terrain visualization, dynamic modelling, and, atemporal and temporal image mapping. Chapter 2 provides a detailed discussion of this topic.

1.4 CHALLENGES IN THE INTEGRATION

As a first step towards seeking a strategy for the integration of remote sensing into the EA system, the major challenges or stumbling blocks, which have been encountered in similar research efforts, need to be examined.

Firstly, several image post-processing operations have to be accomplished in the integration. One of the initiatives of integration is to provide a new data source for national mapping, or, more specifically, to provide continuous-tone and classified national coverage image maps for the EA system. Thus, the effective accomplishment of a number of image post-processing mechanisms forms one of the challenges of integration. These mechanisms include geometrically precise concatenation, image quality control, temporal image matching, the merging of remotely sensed data with data from other sources, and the handling of classification "noise" and data format conversion "noise" of national coverage images based on national mapping standards.

Secondly, the raster and vector formats need to be accommodated. The raster/vector dichotomy has confounded many attempts at integration of remote sensing with GISs (Ehlers et al., 1989). Remote sensing has been almost completely oriented towards a raster approach to data and analysis, while most of GISs, including the EA system, are vector-based systems (although raster-based systems also exist). Both raster and vector forms of spatial data storage and manipulation have inherent advantages and disadvantages (Peucker 1984). For example, geometric or overlay operations are easier to perform in the raster mode, whereas network analysis or topologic operations are more suited to the vector mode. Thus, the appropriate integration of these two data formats, in both the functional aspect and the physical aspect, forms one of the major issues of integration.

Thirdly, a data model capable of dealing with both temporal and spatial characteristics of geographic data should be developed. A variety of geographical information systems are increasingly being employed to manage and analyze spatial distributions and attributes. Temporal as well as spatial considerations are common to many applications. An integrated system, which incorporates both spatial information analysis and image processing functions, should be designed to have the capabilities for managing information about the existing and forecasted status of real world phenomena, and for monitoring change. However, an extensive study of related literature suggests that neither the remote sensing community, nor the GIS development community, has solved the problem of explicitly incorporating the temporal dimension in their respective analyses. The situation existing in these two spatio-temporally related data analysis domains results from the fact that there is no efficient data model or related spatio-temporal query language for the management of spatio-temporal information. The integration of remote sensing into the EA system implies that a large amount of remote sensing images with varied sensed dates will be available for

EA applications. Thus, the temporal issue in data management forms another challenge for integration.

Finally, data error handling is another severe challenge involved in integration. Because of the inevitable data error (i.e., positional errors or the errors in the positional features such as points and lines, and attribute errors or the errors in the values of the thematic attributes (Huang, 1991; Veregin, 1989; Maffini, 1989; Chrisman, 1987), involved in data preprocessing, data input, and data manipulation, the analytical results of a GIS may only have 40 to 50 percent accuracy (Drummond, 1989). The integration of remote sensing into GIS can eliminate some errors of spatial data caused in processes such as map production and digitization. However, the integrated use of spatial information from maps and from remotely sensed data raises another type of error, the sliver polygon error. That is, the boundary data from both map data and remotely sensed data which must coincide with each other do not coincide. This needs to be resolved in order to achieve a quality integration of remote sensing with GIS, in particular with the EA system.

In this research, only two of the challenges described will be dealt with, namely, the first challenge - image post-processing and the second one - raster and vector data accommodation.

1.5 STRUCTURE OF THE THESIS

The thesis presents the research of the integration of remotely sensed data and image processing technology into the Electronic Atlas of Canada. It consists of ten chapters, which correspond to the objectives of this research.

The first chapter provides an introduction to the research, which includes the origin of the topic, the major challenges in the integration of GISs and remote sensing, the objectives of the research, and the structure of the thesis.

Chapter 2 presents an analysis of the basic characteristics of the National Atlas of Canada, of remote sensing data, and of the potential contributions of remotely sensed data to the national mapping program. An overview of the current applications of remote sensing in the National Atlas of Canada is also provided.

An introduction to the EA and the IDRISI systems is given in chapter 3. It covers the system structure, the basic functionality, the data structure, and the hardware and software environment of the two systems. An evaluation of the functionality of the IDRISI system as the support system for the integration is also included. These provide a basis for the design and implementation of the integration.

In chapter 4, an analysis of the potential approaches to the integration of remote sensing into GISs, in particular into the EA system, is presented. The analysis is based on the present technical environments (the EA and IDRISI systems), on the advances in artificial intelligence and expert system technology, and on considerations of further development of the EA system.

Chapter 5 addresses the implementation of the integration of the EA and the IDRISI systems. It includes the selection of the integration approach for this project, the design of data exchange format for the two systems, and the definition of the EA's and the IDRISI's roles in the integration. In addition, the detailed procedures involved in data exchange are provided, and a functionality test on the data exchange is carried out.

Three basic image classification approaches to the integration, namely, the maximum likelihood approach, the minimum distance approach, and the parallelepiped approach, are introduced in chapter 6. The basic frameworks of the ancillary information approach and the knowledge-based approach for image interpretation are also presented. In order to provide users with more efficient mechanisms for an effective extraction of thematic information from remote sensing images, a set of image preprocessing operations is proposed. In addition, the basic procedures involved in image classification on the IDRISI system with supporting information from the EA system, and a comparison of the operational characteristics of the above three image classification approaches are addressed in detail. The comparison aims to provide users with a guideline in the selection of a specific image classifier for their applications.

In chapter 7, a set of image post-processing operations proposed in the integration is presented. These operations are crucial for an efficient and effective integration of remotely sensed data and GISs. The proposed image post-processing operations bridge the gap between the remote sensing and GIS domains.

Chapter 8 provides the methodologies for a set of temporal and atemporal image mapping functions. Namely, for atemporal image mapping, the approaches include the 2-D and 3-D continuous-tone and classified image mapping, 2-D and 3-D topographic image mapping, and 3-D statistic image mapping; for temporal image mapping, the methods include the snapshot approach, the asynchronic approach, and the overlay approach.

Most of the related experiments conducted in the project are presented in chapter 9. The chapter also presents descriptions of experimental data sets involved, procedures required for data processing, and an analysis of experiment results.

A summary of the thesis and the outlines of the results of the research project form chapter 10. Further, the conclusion of the research and recommendations for future work are also addressed. This is followed by the references used in the research.

Finally, the appendix contains a set of remotely sensed data and related ancillary data sources utilized in the project.

CHAPTER 2

POTENTIAL APPLICATIONS OF REMOTE SENSING IN THE NATIONAL ATLAS MAPPING PROGRAM

Previous research has addressed the fact that remotely sensed data can be used as a data source in the national mapping of forest coverage at 1:2 000 000 scale (Palko,1990). However, the other realms, such as snow/ice distribution mapping, of the national mapping program to which remotely sensed data can be applied remain to be considered. This chapter presents systematic analysis of the potential applications of remote sensing in the national mapping program. The characteristics of the National Atlas of Canada and of remotely sensed data are first described. Based on these characteristics, the potential applications of remote sensing in the national mapping program are analyzed. In addition, the current use of remotely sensed data in the national mapping program is discussed.

2.1 CHARACTERISTICS OF THE NATIONAL ATLAS OF CANADA

For nearly eighty years, Canada has had an important tradition of national atlas publication. With the four editions published in 1906, 1915, 1958, and 1974, and the commencement of the fifth edition in 1985, Canada's national atlas program has played an important role in helping Canadians and non-Canadians alike improve their knowledge and understanding of this country.

Atlas Format The first four editions of the National Atlas of Canada were published, in their final form, as conventional bound volumes. Each represented a "snapshot" of Canada at a specific time, and provided a relatively static inventory of the nation's people and

resources. The fifth edition of the National Atlas of Canada departs significantly from its predecessors. The fifth edition of the National Atlas of Canada is significantly different in that it is intended to be more responsive both to the change in Canadian geography, and to the rapidly growing field of information technology. Specifically, the current edition is designed and published as a continuing serial publication of separate but related maps, collectively addressing the geography of Canada (Thompson, 1989). It is designed to be a dynamic atlas of separate map sheets, collectively depicting all aspects of the geography of Canada. Through this, it aims to be more responsive to the demand for specific, up-to-date information.

Atlas Content The content of the fifth edition National Atlas is subdivided into 44 geographic subject realms (NAIS,1989), which encompass all aspects of geographic information relating to Canada. It is intended that every realm will be represented at least by one map, and the number of maps in a realm is theoretically open. This will allow for unforeseeable national requirements for more information in a particular area of interest, and permit the revision of certain high interest maps. These realms cover: physical, environmental, social, cultural, economic, and resource geography. Currently, about 74 maps have been published. Another 28 maps are in production, and about 30 maps are listed as potential contents of the fifth Edition of National Atlas of Canada.

Atlas Map Scale Most maps in the Fifth Edition of the National Atlas of Canada are published at the 1:7 500 000 scale with insets at the scales ranging from 1:500 000 to 1:100 000 000. A few maps showing climate elements that require less detail are presented at smaller scales in multi-map layout. Additionally, the 1:2 000 000 scale has been adopted as a major data gathering scale. All fifth edition maps are based on a Lambert Conformal Conic projection with two standard parallels (49°N and 77°N).

2.2 CHARACTERISTICS OF REMOTELY SENSED DATA

Space remotely sensed data applicable for mapping applications have been readily available in digital format since early the 1970s when Skylab was launched. Since then, there have been several effective space remote sensing programs. These programs include the Landsat satellite program (MSS, TM), the SPOT satellite program (HRV), the weather satellite programs (NOAA AVHRR), the Heat Capability Mapping Mission (HCMM) satellite program, etc. A summary of the basic characteristics of these remote sensing programs is given in Table 1. The basic characteristic presented includes satellite programs, their sensors and spectral bands, spatial and temporal resolutions, and coverage areas of each image.

2.2.1 Radiometric Characteristics

A major characteristic of a remote sensing image is its radiometric wave band it represents (see Table 1). Remote sensing technology has provided with a larger amount of information about the earth than traditional surveying techniques. It has extended mapping scopes from visible to invisible (infrared, microwave), and from the earth surface to the subsurface (microwave remote sensing). Some images are measurements of the spatial disposition of reflected solar radiation in visible (0.4 - 0.7 μm) and near-to-middle infrared (0.7 - 1.3 μm , and 1.3 - 3.0 μm) range of wavelengths, such as Landsat TM, MSS, NOAA AVHRR and SPOT HRV images. Others are measurements of the spatial distribution of energy emitted by the earth itself, these use the thermal infrared wavelength range (3.0 μm - 1.0 mm), e.g., Landsat TM, NOAA AVHRR, and HCMM images. Yet others, such as Seasat images, particularly in the microwave band of wavelengths (1.0 mm - 1.0 m), measure the relative return from the earth's surface and subsurface of energy actually transmitted from the space vehicle itself.

Table 1 The Basic Radiometric and Spatial Characteristics of Major Orbit Remote Sensing Sensors

Orbit Sensor	Band	Wavelength (μm)	Spatial Resolution (m)	Temporal Resolution (Day)	Areal Coverage of Each Imagery (KM)
Landsat	MSS	4	0.50 - 0.60	79	Landsat-1,2,3 Landsat-4,5 18 (D) 16 (D) 185x185
		5	0.60 - 0.70	79	
		6	0.70 - 0.80	79	
		7	0.80 - 1.10	79	
	TM	1	0.45 - 0.52	30	185x185
		2	0.52 - 0.60	30	
		3	0.63 - 0.69	30	
		4	0.76 - 0.90	30	
		5	1.55 - 1.75	30	
		6	10.4 - 12.5	120	
		7	2.08 - 2.35	30	
	SPOT HRV Multispectral Mode			24(H)/26(D)	From 60x60 (nadir) To 80x80 (off-nadire)
		1	0.50 - 0.59	20	
		2	0.61 - 0.68	20	
		3	0.79 - 0.89	20	
	HRV Panchromatic Mode				
		1	0.57 - 0.73	10	
HCMM	1	0.50 - 1.10	600		16(D) 716x716
	2	10.5 - 12.5	500		
NOAA AVHRR	1	0.580 - 0.680		1100	12(H) 2700x2700
	2	0.725 - 1.100		1100	
	3	3.550 - 3.930		1100	
	4	10.30 - 11.30		1100	
	5	11.50 - 12.50		1100	
Seasat SAR	1	0.235 (m)		25	36(H) 100x100

Because of the wavelength extension, remote sensing technology has also considerably enhanced data acquisition capability. Traditionally, spatial data was only collected during daytime and good weather condition. However, present infrared remote sensing technologies can easily gather spatial information both day and night, and microwave remote sensing can collect data in most conditions. In addition, remote sensing technology greatly improves the efficiency of spatial data acquisition. Present space sensors can efficiently provide information for natural resource management, planning and decision making with weekly data coverages (SPOT HRV, Landsat MSS, TM), and daily data coverages (SPOT HRV, NOAA AVHRR) (see Table 1). More importantly, this capability provides dynamic monitoring and modelling of natural resources and environmental changes with efficient data acquisition tools.

2.2.2 Spatial Characteristics

Space remote sensing technology provides users with information about the earth at resolutions from a few tens of meters to a planetary scale (see Table 1). Because of resolution differences, the digital images provided by various remote sensing sensors can find applications at different scales. As a guide, Table 2 relates scales to spatial resolution (based on Richards, 1986). This has been derived somewhat simplistically by considering an image pixel to be too coarse if it approaches 0.1 mm in size on a photographic product at a given scale.

2.2.3 Temporal Characteristics

The final major characteristics of remotely sensed data is its feasible temporal coverage of the earth surface. As shown in Table 1, the current space remote sensors can efficiently acquire spatial information about the earth on hourly (i.e., NOAA AVHRR), daily (i.e.,

Table 2 Suggested Maximum Scales of Photographic Products as a Function of Effective

Ground Pixel Size (Based on 0.1 mm Printed Pixel), after Richards, 1986

Scale		Pixel Size (m)	Sensor
<hr/>			
1:	250,000	25	SPOT HRV, Landsat TM
1:	500,000	50	Landsat MSS
1:	5,000,000	500	HCMM
1:	10,000,000	1 000	NOAA AVHRR

Seasat SAR and SPOT HRV) or weekly base (i.e., Landsat TM, MSS, SPOT HRV, and HCMM). These remotely sensed data provide users with a flexible choice of spatio-temporal data for their specific applications.

2.3 POTENTIAL CONTRIBUTIONS OF REMOTELY SENSED DATA TO THE NATIONAL MAPPING PROGRAM

Space remote sensing information, as previously discussed, can radiometrically, temporally, and spatially provide new data sources for the national mapping program of Canada. However, because of the basic characteristics of remote sensing data, the potential contributions are concentrated in the realms of physical, environmental, human, and resource geography. Specifically, the following domains may benefit the most from remote sensing technology: geomorphology, hydrology, geology, climatology, ecology, phytogeography, environment, agriculture, forestry, urban systems, and transportation networks. The potential applications of remote sensing technology to national mapping can be grouped into three categories: map revision, dynamic monitoring, and new data representation of some topics.

2.3.1 Map Revision

Presently available remote sensing data, such as SPOT HRV, Landsat TM, MSS, and NOAA AVHRR data, can be used for the revision of some of the maps in the National Atlas, such as land inventory map, snow and ice distribution map. The remotely sensed data from the above space sensors are of adequate spatial, temporal and radiometric resolution for national coverage map revision (see table 1). The application of remotely sensed data in this aspect does not generally require that the data be of a high temporal resolution, since most of the maps in the fifth Edition of the National Atlas of Canada are used to reflect geographic phenomena in a monthly or yearly context. Regular map revision does require that the image data be of high quality in geometric characteristics, standard grey equilibrium, and classification accuracy, since these characteristics are fundamental in the provision of authoritative geographic information about Canada (Thompson, 1989). Based on these requirements, on the characteristics of remotely sensed images, and on the content of the fifth Edition of the National Atlas of Canada as well as potential themes in its continuous publication, remotely sensed data from LANDSAT and NOAA space sensors can be used for the map revision of a number of themes, such as forest distribution, land use, urban development, etc.

Forest Distribution A vegetation map is a key map in any national atlas. For a country of Canada's size, however, its development and update is an exceptionally demanding task. Decades of experience in the application of remote sensing to national forest inventory have demonstrated that the technology can play a key role in making of accurate, timely, and cost effective forest evaluations (Talbot and Markon, 1988; Goldberg et al., 1985; Goodenough et al., 1987; Fang, 1980; Beaubien, 1979; Harley, 1979). For instance, Goodenough et al. (1987) conducted the application research on applying Landsat TM data to investigate and update forest distribution maps. Their research results have been operationally applied to the forest management in the province of British Columbia. Recent efforts in national

forest mapping of Canada have further verified this potential. Palko (1990) reports that NOAA AVHRR data can be effectively used for national coverage forest mapping. This is the first pilot project of applying remotely sensed data to the national atlas.

Land Use Inventory and Land Cover Mapping Land use inventory and mapping are fundamental realms in a national mapping program, since it is important in the understanding of national scale land use and in land use planning. In this respect, experiences have fully demonstrated the applicability of remotely sensed data to land use mapping (Colwell, 1983; Wharton, 1987; Civco, 1989; Moller-Jensen, 1990). One of the examples is the application of remote sensing in nationwide base-line mapping of land use and land cover mapping conducted by the U.S. Geological Survey (USGS). Since 1974, USGS has engaged in using remotely sensed data to map land use and land cover at a scale 1:250 000. By the end of 1980's, all of land use and land cover maps of the nation had been completed. The availability of multispectral NOAA AVHRR data (and data from similar meteorological satellites) on a regular basis has provided the capability to compile broad-scale land cover maps and data directly (Townshend & Tucker, 1984; Tucker et al., 1985). For instance, Tucker et al. (1985) effectively used NOAA AVHRR data to produce a land cover map of Africa.

Snow and Ice Distribution Snow and ice on the Earth's surface are very distinctive features which can be detected readily with a variety of remote sensing techniques. For mapping snow and ice distribution, space remote sensing technology provides several advantages over ground-based and aircraft remote sensing approaches, including a larger-area viewing and data acquisition efficiency. Landsat and NOAA meteorological satellites have provided a large amount of useful data on the areal extent of snow cover, and these data have been successfully used for snow mapping and snowmelt-runoff estimation (Rango and Peterson, 1980). For ice study, NOAA images have been found to be useful in tracking ice-flow motion and in identifying ice cover, type, and distribution (Waterman

et al., 1980; McMillan and Forsyth, 1976). For instance, as indicated by Waterman et al. (1980), NOAA can be effectively used for small scale map production of snow and ice distribution in Canada. Because of the vastness of the surface snow and ice resources in Canada, monitoring them from space is desirable.

Wetland Distribution Wetlands are an important component of the hydrologic system. Increased public concern over the environment in recent years has led to the enactment of national and local legislation for the protection of both inland and coastal wetlands (Mungall and McLaren, 1990). Considerable research has been conducted on applying remotely sensed data from NOAA and Landsat satellites to study and map wetlands (Carter and Anderson, 1972; Carter and Schubert, 1974; Carter et al., 1979; Gilmer, et al., 1980; Klemas et al., 1975; McEwen et al., 1976). Carter and Schubert (1974), for example, used Landsat data supported by ground-level spectrometer measurement to map the wetlands of the Chicoteague Bay in Virginia at scale 1:20 000; Klemas et al (1975) used both Landsat data and Skylab photographs to study the coastal zone of Delaware. These research efforts have demonstrated that remotely sensed data can be effectively used for local and national coverage wetland mapping.

Glacier Distribution Space remote sensing technology has long been used to document the position of glaciers, to illustrate types of glaciers and associated features, and to map planetary and local scale glaciers. Decades of research on the issue have proved that the space remote sensing technology is one of the most efficient and effective approaches to study and map the distribution of glaciers on the earth surface (Williams et al., 1975, 1979, 1981, 1982; Swithinbank and Land, 1977; Berg, et al., 1982). For instance, Volmarans and Krynauw (1981) addressed the use of Landsat MSS for mapping glaciers distributions at scale 1:250 000 needed for basic geological applications. Berg et al. (1982) also considered the compilation by NOAA and USGS of a 1:5 000 000 scale image mosaic of Antarctic glaciers through the use of NOAA AVHRR images.

Sea-Ice Distribution Sea-ice is one of the themes studied in the climatology section of the National Atlas of Canada. With increased shipping activity and petroleum exploration in Arctic waters, the need for accurate and timely sea-ice information has increased. Several efforts have been taken in applying remotely sensed data to study sea ice (Zwally et al., 1983; Dey, 1978; Campbell et al., 1975; Meier and Evans, 1975). Mullane (1980) addressed overall experiences of using NOAA and Landsat images for sea ice study at national scale in Canada Ice Forecasting Center, and concluded that the remotely sensed data, especially the NOAA and Landsat data, is the only practical way to map sea ice on a regional, repetitive basis.

2.3.2 Dynamic Monitoring

Another potential application of remote sensing in the national mapping program is the dynamic monitoring of spatial phenomena. There are generally two reasons for dynamic monitoring of spatial phenomena. One is to analyze and evaluate the dynamic situation of specific phenomena and their possible impacts on the environment. The other is to predict possible trends of phenomena. The temporal characteristics of remote sensing data, together with image analysis technology, provides dynamic monitoring of spatial phenomena with an efficient and effective data acquisition and analysis tool. According to their spatial and temporal resolutions and the requirements for temporal national mapping applications, current available remotely sensed data can be applied to the monitoring of such spatial phenomena as acid rain, snow, sea ice, icebergs, vegetation, floods, agro-climate, and forest resources.

Studies of Acid Rain Acid rain and its impact on the eco-environmental system has drawn increasing academic and political attention around the world. Canada is one of the countries which has undertaken serious studies of the impacts of acid rain. Remote sensing

technology has been used for detecting and investigating acid rain distribution and effect on the eco-environmental system (Mungall and McLaren,1990; Milton and Mouat,1989). Because of the advantages of repetitive coverage, remotely sensed data can be efficiently used in the direct and indirect monitoring of acid rain development and in the analysis of its impacts.

Dynamic Snow/Ice Coverage Changes in snow coverage influence agricultural and other economic activities, such as agricultural irrigation, hydro-energy, and flood control. Therefore, it is significant to dynamically represent this information in the Electronic Atlas in order to provide agricultural managers, water supply managers, hydro-energy managers, etc., with accurate and up-to-date snow/ice change data. Frequent repetition of surface coverage is a crucial requirement for remotely sensed data to be effective for these applications. For this dynamic application, data acquisition tools should have high temporal efficiency. Among presently available space sensors, the NOAA AVHRR, Landsat MSS, TM, and SPOT HRV, which provide daily, weekly or monthly coverage of snow/ice distributions, are the best data sources for this purpose.

Dynamic Distribution of Sea Ice and Icebergs Because of the increasing research and activities involved in Arctic navigation, it is becoming more and more important to provide users with dynamic distributions of sea ice and icebergs. In this respect, space remote sensing can play an important role in dynamically monitoring change of sea ice and icebergs distributions. The application may include using remotely sensed data to investigate dynamic distribution of sea ice, to detect and track icebergs as they enter shipping lanes. Kirby and Lowry (1981) published radar images of icebergs and discussed their interpretation of icebergs motion, types, etc. Steffan and Schweiger (1990) carried out research on applying Landsat MSS and NOAA AVHRR data to study sea ice characteristics, such as sea ice type and stage of developments, and indicated that space remote sensing techniques are efficient and effective tools in the study of sea ice and that

the presentation of spatial dynamic distributions of sea ice and icebergs for such a vast area can only be achieved by using space remote sensing technology. Other researchers, such as Sabins (1987), Cracknell (1981,1982) and Ketchum (1984) also conducted some related research on the application of remotely sensed data in studying icebergs.

Biospheric Environment Monitoring (Vegetation) Monitoring of global warming, air pollution, deforestation, land over-use, and desertification have become active research issues in both the academic and political domains. This application requires that data acquisition approaches be of proper temporal and spatial resolution. Space remote sensing technology has played an important role in the related research (Achard and Blasco, 1990; Choudhury et al., 1987; Choudhury, 1988; Justice et al., 1986; Townshend and Justice, 1986; Hielkema et al., 1986). The potential value of using remotely sensed data for monitoring vegetation condition were also demonstrated by the research conducted by Townshend and Justice (1986), Hielkema et al. (1986), who used NOAA AVHRR data to monitor the grasslands of semi-arid Africa, and Tucker et al. (1984), who effectively used NOAA AVHRR data to examine crop phenology and agricultural practices in the Nile Delta.

Flooding Monitoring and Impact Analysis Efficient acquisition of dynamic data is particularly important in the monitoring and impact analysis of flooding. In this aspect, space remote sensing technology has played a very important role in the delineation of flooded areas and the detection of dynamic change of floods (Deutsch and Ruggles, 1974; Philipson and Halker, 1981; Kruus et al., 1981; Sabins, 1987; Yamagata and Akiyama, 1988). For instance, Philipson and Halker studied the application of Landsat MSS data to the delineation of flooded areas. They concluded that extraction of flooding information was very efficient through the use of remotely sensed data and that simple visual interpretation of MSS band 7 images was as accurate as manual interpretation of multi-band composite image and also as accurate as digital analysis of MSS band 7. Flooded areas, in

most cases, are cloud covered and rarely recorded on Landsat and NOAA satellite images. In this case, radar remote sensing provided by such platforms as Radarsat, in the near future, with its cloud-penetration capability, is well suited to monitor floods.

Agro-climate and Disease Monitoring Research has demonstrated that remote sensing can be used for monitoring soil moisture (Soer, 1980; Schmugge, 1979; Eagleman and Lin, 1976; Idso et al., 1975), evapotranspiration (Regineto et al., 1976; Kanemasu et al., 1977), and agricultural pests and diseases (Gausman et al., 1975). For instance, Eagleman and Lin (1976) carried out an analysis of the Skylab data and compared the brightness temperature with estimates of soil moisture over the radiometer footprint. They obtained a correlation of 0.96 with data obtained during five different Skylab passes over Texas, Oklahoma and Kansas. Kanemasu et al. (1977) effectively conducted research on the estimation of evapotranspiration of winter wheat using a model which incorporated Landsat estimated leaf area index, and concluded that remote sensing techniques are a useful tool in the estimation of evapotranspiration.

Forest Fire Monitoring Remote sensing technology has long been used for dynamically monitoring forest fires, because of the temporal, spectral, and spatial characteristics of remote sensing. For example, the phenomena on forest fires is a very distinct feature in infrared remote sensing (Miller et al., 1986). For instance, Miller et al. (1988) conducted successful research on applying AVHRR data in an information system for fire management in the Western United States. With Landsat, SPOT and NOAA infrared satellite images, forest fires can be easily detected. The technology will continue to be an efficient approach for this application.

2.3.3 New Data Representation

Digital remote sensing imagery is basically recognized as the objective reflectance of the real world. Compared with conventional choropleth maps, remote sensing images provide users with more realistic and flexible representations of the real world. Such a data source, together with related digital image processing techniques, provides resource planners and managers with a new and realistic information representation method. Especially, satellite imagery, combined with a DEM, can be used to produce realistic perspective views of the terrain, which can facilitate resource management, planning, and environmental impact analysis. By using video recording techniques, it is even feasible to simulate passage through the terrain by foot, vehicle, or aircraft (Starr, 1990; Gimblett, 1989; Turner, 1988; Hibbard and Santek, 1989). These advantages of remotely sensed data can also apply to national mapping. Using remote sensing data, a variety of image maps, as described below, can be produced, and thus, geographic information can be visualized realistically.

Temporal and Atemporal, 2-D and 3-D, Synthetic and Non-Synthetic Image Mapping

Using image processing techniques, 2-D and 3-D national coverage synthetic and non-synthetic image maps can be generated. Non-synthetic image maps are the image maps which are directly produced from continuous-tone or classified remotely sensed images. While synthetic image maps are the maps which are produced based on continuous-tone or classified remotely sensed images, overlaid with thematic and topographic data from the EA system.

Image mapping using remotely sensed data provides the applications of national coverage mapping with several advantages over traditional cartographic mapping. Firstly, from the perspective of data representation, continuous-tone remote sensing image maps provide a more realistic representation of the real-world than traditional maps. They can more objectively reflect the distributions of land coverages with low generalization. Together with spatial and non-spatial information from EA's database, a synthetic image map can be easily created. Secondly, from the temporal perspective of national mapping, the frequency

of coverage and related time period involved in the satellite image collection (daily for NOAA and SPOT data, weekly for Landsat and SPOT data) is an important advantage of remote sensing image mapping in depicting terrestrial cover conditions over large areas of the earth's surface. Traditional cartography usually uses spatial data from data sources other than satellite remote sensing. It, in most cases, takes longer time to acquire the necessary national coverage data required for national mapping. Also, since more procedures are involved in the creation of national coverage maps, the data error potentials are increased, and the efficiency of map production is not satisfactory for dynamic phenomena monitoring.

Among all the above applications of map revision, dynamic monitoring, and new data representation, particular attention should be paid to the utilization of NOAA AVHRR imagery in mapping land-covers at national, continental or even global scales. During the last decade, substantial progress has been made in using NOAA AVHRR data for mapping land covers (more examples are presented by Townshend and Tucker, 1984, Goward et al., 1985, Roller and Colwell, 1986, Townshend et al., 1987, Lyoyd, 1990, Eidenshink et al., 1991, and Loveland et al., 1991). AVHRR data only have moderate spatial resolution (1 km) when compared, for example, to Landsat's 80m for MSS and 30m for TM, or SPOT's 30m for multispectral and 10m for panchromatic data. AVHRR data are, however, collected more frequently, with virtually the entire globe imaged twice each day. The high frequency of coverage enhances the likelihood that cloud-free observations can be obtained for specific temporal windows, and makes it possible to monitor change in land cover conditions over short periods. Moreover, the moderate resolution of the data makes it feasible to collect, store, and process national, continental or global data sets. This is particularly important for a country of Canada's size.

2.4 CURRENT USE OF REMOTELY SENSED DATA IN THE NATIONAL ATLAS MAPPING PROGRAM

The application of remotely sensed data in the national atlas mapping program of Canada was initiated in 1989 through the Manitoba Pilot Project in the National Atlas Information Service, Geographic Services Division, Canada Center for Mapping. The objective of this project was to test the suitability of using NOAA AVHRR imagery as an up-to-date source for mapping forested areas in Canada and, potentially, for the mapping of other forms of vegetation cover (Palko, 1990).

Experience with this project proved that the current expertise and technology make NOAA AVHRR imagery a viable data source for the National Atlas and for other similar thematic mapping needs. The experience also demonstrated several advantages of applying space remotely sensed data in the national mapping program. First, working with satellite data of 1 km spatial resolution, it is possible to achieve the resolution of four or more pixels for a minimum area of thematic information. This resolution is appropriate for National Atlas presentations. Secondly, the number of images required was quite manageable and affordable. About six NOAA AVHRR images are needed for the Canada vegetation project. Thirdly, since only a few images were needed for the national mapping and the coverage is frequent, a much shorter time period is needed to collect a complete set of cloud-free images. The frequency of coverage and related time period involved in satellite imagery collection is very important for depicting cover conditions over large areas of the earth's surface, especially for monitoring change.

CHAPTER 3

MAJOR SOFTWARE AND HARDWARE ENVIRONMENTS OF THE INTEGRATION

The integration of remote sensing into the EA is accomplished within an environment that is mainly composed of two systems: the Electronic Atlas of Canada and the IDRISI system. The IDRISI system is used in an attempt to provide an image analysis support system for the integration. In order to examine its suitability, a test was carried out according to the requirements of the integration. This chapter gives an introduction to these systems as well as the evaluation of the system test.

3.1 THE ELECTRONIC ATLAS OF CANADA

The concept of the Electronic Atlas of Canada (EA) was initiated in the Geographical Services Division of Energy, Mines, and Resources Canada in the early 1980's. The prototype system was developed to demonstrate the potential benefits to be gained from the application of computer technology to National Atlas information (Siekierska, 1983). After extensive evaluation of the system by potential users, a decision was taken to further develop the system's capabilities and to upgrade the prototype into a workable platform and transfer to a cartographic production area for further testing and refinement.

The EA system is being developed as an analytical and map design component of the National Atlas Information System (NAIS), with its principal application directed to the thematic elements of the National Atlas Database. The intent of this development is to provide geographic and cartographic staff with electronic mapping capabilities incorporating a flexible topic selection, map creation capability and analytical tools. This will augment the scope and potential of current activities by permitting geographic and cartographic staff to more easily perform analyses and comparisons of diverse data types for use in the planning, priority setting and decision making processes (Thomson, 1989). In this section, several aspects of the system are presented, namely, the system structure,

the major functionalities, the data format, the data set, and the hardware and software environments.

3.1.1 System Structure

The EA system consists of nine processes: the Atlas Process, the Display Process, the Color Process, the History Process, the Regen Parent Process, the Regen Interface

Figure 3.1 The EA System Structure

Process, the Regen Process, the Database Parent Process, and the Database Process (Cardinal Consulting, 1990). Figure 3.1 illustrates this basic structure.

The Atlas Process is the main process of the EA system. It is responsible for performing all application level processing within the EA system. This includes various definition functions (element, attribute, and symbology), various calculation modules (area, distance,

and statistical), the data entry and data update functions, the query functions (attribute and spatial), and various utility functions.

The responsibility of the Display Process is to perform all display level processing of image data within the EA system. This includes all the functions that are either directly or indirectly used to maintain or interact with the windows that actually display map images. Namely, it includes such functions as overlay display priority selection, enabling and disabling of overlays, symbology selection (for points, lines, and polygons), color selection, text control, and highlighting control, as well as various support functions.

The user interaction mechanism for selecting and modifying colors is provided by the Color Process. The process simultaneously tracks color change in real time of up to three different color palettes.

The History Process is mainly used for maintaining the history window and for providing access to all the previous queries. The user may freely go forward and backward through the history lists to view the results of any query previously made.

The responsibility for receiving requests from the Display Process and starting a Regen Process that can serve those requests is taken by the Regen Parent Process.

The Regen Interface Process is responsible for buffering the individual regeneration requests between the Display Process and the Regen Process. This then allows the Display Process to continue with other activities, while the image regeneration is in progress.

The Regen Process performs the conversion of data from vector format into raster format. This conversion process is initiated by the Display Process and proceeds independently.

The Database Parent Process is responsible for receiving requests from client process and starting a Database Process that can serve those requests.

Creating, maintaining, and responding to requests for information for both the vector and attribute database are the responsibility of the Database Process.

3.1.2 System Functionality

Cartographic Functions

Cartographic functionality is emphasized in the EA system. Several special cartographic functions are provided in the system (Siekierska and Taylor, 1991). One is the map structuring function, which permits selection of information stored in the system's database, and the creation of customized maps. The second function is the map design function, which allows the user to interactively design a map by specifying the display criteria for a given subject, and by selecting symbols and colors. For choropleth maps, the system calculates histograms in order to facilitate the interactive selection of class intervals. Another important feature of the cartographic functions is the color manipulation capability. Colors can be assigned to particular map elements in a static way, which means that individual colors may be selected, or in a dynamic way, meaning that the user selects start and end colors of a given scale, and all intermediate colors are automatically calculated by the system. The dynamic color function allows for the use of animation or blinking of selected features in map displays.

Query and Analytical Functions

Spatial query and analytical functions of the EA are similar to the functions present in general GISs. There are mainly two types of queries in the EA: attribute query and spatial

query. Attribute query allows the selection of elements based on their ability to satisfy a specified set of criteria. All types of attributes can be examined, including numeric, textual, and special (logical, position, time). Users can graphically select, on the electronic display, a map element about which they wish more information (Sickierska and Taylor, 1991). The spatial query function permits the user to select map elements based upon their relationships with other objects. This function deals with all kinds of map elements (point, line and polygon), and responds to queries on both nearness and inclusion of either an entire object, or a part of an object (Cardinal Consulting, 1990). The analytical functions provided in the EA include attribute synthesis functions and a range of spatial metric calculation functions (Cardinal Consulting, 1990). The attribute synthesis functions deal with statistical calculations, including means, totals, standard deviations, and frequency histograms, based on the attributes of spatial objects. The metric calculation functions allow the user to perform various calculations involving length, area and distance of spatial objects.

Spatial Modelling

On the basis of the cartographic and analytical capabilities, the system permits two types of simulation modelling (Siekierska and Taylor, 1991). One involves historical reconstruction, for example, the territorial evolution of Canada. The function can be used to visually model spatial change of geographic phenomena. The other is the "prediction" of the future evolution of certain processes, for example, the depletion of oil reserves.

Data Input

The EA was intended to be an analytical and map design component of the National Atlas Information Service (NAIS). NAIS has been described as "..... a program of the

Geographical Services Division, Energy, Mines and Resources Canada, initiated in response to the need to produce multi-theme maps and geographic information of Canada, to a consistent standard, in a digital environment, to serve the needs of the federal government" (pp.62, Thompson,1989). NAIS will include three principal data bases: the National Toponymic Data Base, the National Cartographic Data Base, and the National Atlas Data Base (Thompson, 1989). The National Toponymic Data Base is an integrated digital and analogue database of geographic names information. It presently contains over 400 000 toponyms and associated names information, of which 75% are names officially approved by the Canadian Permanent Committee on Geographical Names. The National Cartographic Data Base, when complete, will comprise the digital records of the International Map of the World and Canada Base Map Series, which are required to ensure the detailed and topologically sound framework used to construct the ranges of maps needed for a variety of NAIS uses. The National Atlas Data Base contains the conventional maps of the fifth edition and will incrementally and increasingly contain the digital data used to compile the later maps of the fifth edition. The supporting systems for NAIS are the ARC/INFO geographical information system and the relational database management system ORACLE. In such an environment, the Electronic Atlas coverages are generated from the output of ARC/INFO using an ARC-CCSM translator, developed at the Nova Scotia College of Geographical Sciences.

Data Storage

The Electronic Atlas internal database, which has been established by down loading data from the NAIS database, has been specifically designed to store and handle cartographic data (Siekierska and Taylor, 1991). The data is organized using three types of files: positional files which organize the spatial positions of objects with fundamental topologic properties, attribute files which store the thematic values associated with each geographic

object; and cartographic specification files containing sets of symbols and relevant rules, such as generalization rules and color manipulation rules, for data display. All three types of files are utilized to derive output files, namely the display and analysis files.

3.1.3 Data Format

In the EA system, data related to the position of spatial objects are organized in vector format. The vector data, together with attribute files and cartographic specification files, are permanently stored in the EA's database. The output files, which can be permanent or temporary display and analysis files, are organized in raster mode. This allows for flexible overlay of multiple maps.

3.1.4 Data Sets

Information found in the National Atlas of Canada forms the potential data sets for the EA. The present prototype system has incorporated a representative selection of topics, ranging from the economic geography maps, such as Oil and Gas Fields, Oil and Gas Pipelines, Oil Refineries, Coal Mines and Coal Bearing Formations, through physical geography maps such as Soil Capability for Agriculture and Wind Risk Erosion, to human geography maps, such as Indian and Inuit Settlements and Communities. The scales range from 1:7.5M to 1:25M.

3.1.5 Software and Hardware Environment

The present EA system is capable of running on any of the Sun computer workstations, under SunOS operating system. It requires the presence of a color monitor capable of displaying up to 256 colors. In addition, the following minima are required to ensure a

reasonable level of performance: minimum of 5 MIPS of CPU speed, minimum of 4 Mb of main memory, and minimum of 150 Mb of local disc storage.

3.2 THE IDRISI SYSTEM

IDRISI is a raster-based geographic information analysis system developed at Clark University (Eastman, 1990). This section describes its system structure, functionality, data format, and software and hardware environment. In addition, based on a functionality test carried out for the integration, the system is evaluated according to the requirements of an image analysis system.

3.2.1 System Structure

The IDRISI system is a module-based system. By using independent modules linked by a simple data structure, the system allows users to develop their own modules with minimal regard for the internal workings of the IDRISI modules in the core set. The IDRISI program modules fall into one of the following three groups:

1. CORE modules. These modules provide fundamental utilities for the entry, storage, management, display and analysis of raster and vector image;
2. RING modules. These modules provide extensions commonly associated with a major analytical mode. The functionalities of the modules include the basic analytical operations involved in GISs, spatial statistics, and image processing.

3. **PERIPHERAL** modules. These modules provide basic facilities for data conversion between the IDRISI system and other cartographic and GIS systems, and the facility to build new modules.

The basic system structure is shown in figure 3.2

Figure 3.2 The IDRISI System Structure

3.2.2 System Functionality

System Operations

The system operation functions provided by the IDRISI system include facilities to change the prevailing IDRISI operating environment, to list the names and titles of all image, vector, and value files, to list color palette files in the active data directory, and to describe the contents of any image, vector or value files.

The IDRISI system also provides interactive and default system parameter modes for most operations. Users can interactively change operation parameters in data processing, or follow system default parameters. In addition, users can work with the system in two operation environments, the command-based and the menu-based interfaces. Thus, experienced users can use the command-based environment with their system operation, whereas the menu-based interface provides inexperienced users with a more friendly environment for their applications.

Data Input and Output

The system can accept data from three different devices: keyboard, table digitizer and raster scanner. Since the IDRISI system is a grid-based geographic analysis system and all analyses are carried out on images stored in raster format, the system also provides basic conversion functions to transfer spatial data (points, line or polygons) from vector format to raster format and vice versa, and to convert data among all of the image storage formats supported by the IDRISI system (i.e., byte, integer and real data types, ASCII, binary and run-length code file structures).

The data output in the IDRISI system can be in two different forms, i.e., ASCII characters and color image on CRT, or hard copy of ASCII and image on printers (all of the outputs can be either in vector or raster format).

Data Manipulation

The IDRISI system provides several basic facilities for data management. These include: image expansion, image contraction or reduction, extraction of user defined image windows, on-screen image query, image transposition by row or column reversal or by rotation, image concatenation, image resampling, and screen image dump function. These

facilities provide users with assistance in image classification, registration and geometric rectification.

The system also provides several analytical functions for image operations which include:

a) overlay operations that undertake pixel addition, subtraction, multiplication, division, and exponentiation of paired images; b) image scalar that includes the operations of adding, subtracting, multiplying, dividing, and exponentiating pixels by a constant value; c) reclassification of image; and, d) filtering operations in which mean, median, mode, edge-enhancement, low-pass, high-pass, and user-defined filters are accommodated.

GIS Functions

The GIS ring functions are analytical in nature. The functions provided by the system include only the most fundamental operations associated with concepts of distance, routes and corridor analysis, surface analysis, regional delineation, and line generalization. In addition, the system provides several fundamental analysis functions for spatial statistics, which include basic statistical functions of trend analysis, computation of density, variance-mean ratio of quadrat cell counts, compactness ratio of polygons given corresponding area and perimeter images, and Moran's I first lag autocorrelation analysis. The system also provides the function to transform a set of irregularly distributed points into Thiessen polygons.

Image Processing Function

The image processing module of the IDRISI system is developed for the computer-assisted interpretation of remote sensed imagery. The related functions include: creating signature for training sites, downloading of Landsat CCT-X data, converting raw values to calibrated

radiance for Landsat image, one unsupervised image classifier (the image clustering function), and three supervised classifiers, namely, the parallelepiped approach, the minimum distance approach, and the maximum Likelihood approach.

Interfaces with other GISs and Remotely sensed data Sources

The IDRISI system provides several interfaces with other cartographic systems or GISs, such as ARC/INFO, pMAP, ERDAS and ODYSSEY systems, and USGS DIG and CTG data. The facilities make the system flexible in exchanging information with other GISs. However, the interfacing capability of the IDRISI with remotely sensed data sources is relatively weak. At present, the system only provides an interface with Landsat CCT-X images.

3.2.3 Data Format

The IDRISI system uses two basic data formats, namely, vector and raster formats, to represent spatial information. The data organized in both of the formats can be stored in any combination of three data types (integer, real and byte) and three file types (ASCII, binary and packed binary). Each data file also has an accompanying documentation file which records information about the data type as well as other features such as the number of row and column, title, etc.

3.2.4 Software and Hardware Environment

The IDRISI system is a PC-based system. It runs on IBM compatible computers with PC- or MS-DOS operation systems. The IDRISI system runs on most microcomputers based on the Intel 8086, 8088, 80286, 80386 (or later) family of microprocessor chips running

MS-DOS 2.11 or greater. Minimum requirements are 512K of internal memory (RAM) and two floppy disk drivers. For display, a CGA graphics adaptor is required. A dot-matrix or ink-jet printer is required for hard-copy output. However, as suggested by the system developers, the recommended hardware for IDRISI version 3.2 or later is 1 Meg or more of internal memory, a 20 Meg or larger hard drive, and a EGA or VGA graphics adaptor. In the integration, a COMPAQ 386 computer is used as the basic hardware platform in supporting the system operations.

3.2.5 Evaluation of IDRISI System as Support for the Integration

In order to provide an efficient and effective support for the integration of remote sensing into the EA system, a capability test of the IDRISI system was conducted. The test involved three aspects of the IDRISI system functionality: the capability for fundamental image operations, the capability for image processing, and the capability for data exchange with other GISs (Huang, 1990).

The test showed that the IDRISI system, as a support system for the integration, has strengths and weaknesses in the following respects:

The system provides the following functions:

- 1) Command-language interface and menu-driven interface. Users can easily access the IDRISI image manipulation function through both command-language interface and menu-driven interface.
- 2) Interactive and default parameter system execution environment. By adopting default parameter execution environment, users do not need to interact with system parameters while running the IDRISI system. The environment is particularly useful for inexperienced users. However, for experienced users, the IDRISI

system provides interactive operation environment, with which users can very easily change the system operational environment according to their particular requirements.

- 3) Flexible data input and output facilities. The system can input data and output analysis results from several different devices. For instance, the system can accept data from keyboard, table digitizer and raster scanner, and can output analysis result from printers, CRT and plotters.
- 4) Rich image arithmetic operations. The IDRISI system provides a wide range of analytical functions for image operations, which cover image overlay, image scalar, image reclassification, and image filtering operations.
- 5) Dynamic screen query, digitizing and screen dump, window and dynamic zooming facilities. By using these functions, users can easily access their required image information, extract useful image features, create specified images, etc.
- 6) Basic image classification approaches and spatial domain filters. These functions are fundamental for extracting thematic information from remotely sensed data for national atlas mapping.
- 7) Facilities for data format conversion, spatial resolution standardization and reprojection. These facilities can effectively be used for image post-processing.
- 8) Flexible system interfaces with other GISs. The IDRISI provides several system interfaces with other GISs, such as ARC/INFO, pMAP, ERDAS, etc. These facilities enable system users to share and/or exchange data with other GIS systems.

The maximum size of each image file can be up to 32000 x 32000 pixels. This capability is sufficient for the national mapping purpose, since a national coverage AVHRR image with 1 KM resolution includes 6000 x 6000 pixels. Such an image needs 36 Meg for storage if the image is of 255 grey levels. The data value of each pixel can range from -32768 to

32768, which allows a large dynamic range of image classes or values of thematic data to be processed in national mapping. Also, IDRISI can accommodate up to seven bands of images and extended ancillary data layers for image classification in three classification approaches. This capability allows EA's users to incorporate, in addition to five basic AVHRR bands, at least two extended layers of ancillary data in image classification. This feature is useful in improving image classification accuracy if effective ancillary data are available.

However, the system is insufficient in the following respects as a supporting system for the integration:

- 1) Limited capability in raster-to-vector conversion. The system can only convert the area image objects with the boundary length less than 4000 pixels. This limitation enforces users to partition large images into smaller data sets in data format conversion, and then to concatenate all the results after the processing. This obviously decreases the efficiency in raster-to-vector conversion.
- 2) Image batch processing capability. Lack of this capability requires the user to be involved in executing previously defined processing scenarios all the time and in extensive processing requiring lengthy computation and larger volumes of data.
- 3) System functions for monitoring and controlling image processing process. For most of image processing operations, the system does not provide mechanisms for dynamic resource allocation, interrupt handling and checkpoint/restart operation. In consequence, the interaction between user and the IDRISI system is in a blind situation.
- 4) Automatic image matching mechanisms. The lack of this mechanism makes it difficult to precisely match or concatenate national coverage images.

- 5) Mechanisms for heuristic information image classification. The IDRISI system does not provide this mechanism. This is considered as a more effective methodology in image analysis, since it can take into account, in addition to spectral information, other spatial and non-spatial constraints in image interpretation.
- 6) Mechanisms for generalizing classification "noise". Handling classification "noise" is necessary in order to provide qualified data for national mapping. Unfortunately, the IDRISI system does provide such a capability. Data format conversion "noise" handling can be achieved through the use of line generalization. However, because of drawbacks of the IDRISI data structure, the processing results are not satisfactory (details are discussed in Chapter 7 (Image Post-Processing) and Chapter 9 (Experiments)).
- 7) Limited options of spatial filtering (or called convolution) windows. The system only provides a 3 x 3 template. In some cases, such as extracting some spatial linear patterns, larger filtering windows (e.g., 5 x 5, 9 x 9 or even larger templates) are needed. Moreover, filtering mechanisms in frequency domain also need to be developed. These mechanisms are complementary to spatial domain image processing. They are necessary in order to provide the user with more flexibility in image processing.

Based on these strengths and weaknesses, the IDRISI system, from the perspective of image processing and system interface with other GISs, was evaluated as a basically suitable system for supporting the first level of integration task. However, in order to provide more effective and efficient support, there are two potential approaches to improve the remote sensing image processing capability for the first level or higher levels of integration. One is to improve IDRISI's system functionality in the following aspects:

- 1) data manipulation functions, including: the function for automatic image matching and the capability of image batch processing;
- 2) image processing functions, including: the mechanism for thematic data extraction with heuristic information, and the functions for generalizing classification and data conversion "noise";
- 3) island polygon handling capability. This capability is fundamental in the integration, since the EA system is incapable of accepting spatial data with island polygons, which are commonly seen in the thematic layers derived from remote sensing images.

The other approach is to use a more powerful image analysis system, such as PCI EASE/PACE, DIPIX ARIES, I²S, and ERDAS, as a supporting system for the integration task. These image analysis systems provide strong image processing capabilities in terms of:

- (a) system capabilities for interactive and batch processing;
- (b) a flexible system user-interface;
- (c) system functions to monitor and control processing operations;
- (d) capabilities for chaining processing tasks into multi-step jobs;
- (e) capabilities for automatic cataloging of data sets; and
- (f) a set of utility programs to handle service functions.

The latter approach will provide more effective supports for integrating remote sensing into EA, and may lead to a higher level of integration.

CHAPTER 4

ANALYSIS OF INTEGRATION APPROACHES

The integration of remote sensing into the EA system may be accomplished in several ways. Three possible approaches, ranked at different levels, are analyzed in this chapter. These approaches are based on the ideas discussed in Ehlers et al. presentation (1989), on the present hardware and software environments of the EA system and remote sensing image analysis systems, on the advances in artificial intelligence and expert system technology, and on the further development of the EA system.

4.1 FIRST LEVEL INTEGRATION APPROACH

The objectives of the first level integration are twofold. The first is to introduce remotely sensed data into the EA system as a new data source for national mapping. The other is to provide the EA system with supplementary functions for remote sensing image processing, image post-processing, and image mapping. In order to achieve these goals, the integrated environment should have the following capabilities:

- a) *The capability of displaying both the EA's data and the remote sensing images on the same hardware platforms:* This is the fundamental goal of this integration level. It will allow users to easily exploit both the EA's data and the remote sensing images according to their application requirements.
- b) *The capability of moving the results of image processing, such as thematic maps and extracted lines, from the IDRISI system to the EA system.* This capability will allow for the assignment of attribute values to the polygons converted from images. This is necessary because of the difference in specification between the EA's data and the thematic information converted from remote sensing images. It is also an indispensable function needed in the integration, since the thematic data or image maps must be integrated into the EA system.
- c) *The capability of moving the results of EA's spatial data and analysis results to the image analysis system for supporting the validation of image analysis results and the image registration.* The validation of image analysis results is a necessary step in applying the results to other applications, such as urban planning and resource management. It will allow users to understand the confidence level of analysis results. In most cases, the relevant operations need to be accomplished by using historical

spatial data stored in the EA system. Also, the EA's spatial data is particularly useful in the geometric registration of images to a common base. Therefore, the capability of sending the EA's data to an image analysis system is needed in the integration.

- d) *The capabilities of conducting image post-processing (e.g., image "noise" handling and quality control of a national coverage image):* Establishment of these capabilities is one of the key issues in the integration. These capabilities are the fundamental facilities to bridge gaps between the GIS and remote sensing domains (Colwell, 1983; Ehlers et al., 1989; Lauer et al., 1991).
- e) *The capability of generating atemporal and temporal image maps:* This is the fundamental capability needed in the integration. With this function, the form of national maps can be extended from traditional cartographic representations to more realistic and dynamic image presentations, such as 2-dimensional and 3-dimensional national coverage image maps, and temporal image maps.

As discussed in Chapter 3, the EA and the IDRISI systems are running on different hardware and software environments which are incompatible with each other. Therefore, data exchange is an important issue in accomplishing the integration. The methodologies of image mapping will be another issue to be resolved. Figure 4.1 shows the basic framework of the first level integration, which is also called a parallel integration approach. In this level of integration, both the EA system and an image processing system can run on different hardware and software environments, while the interaction between two systems is achieved through system interface which is a crucial point for the first level integration.

Figure 4.1 The Framework of the First Level Integration

4.2 SECOND LEVEL INTEGRATION APPROACH

A more advanced integration of remote sensing into the EA could be accomplished in such a manner that the integrated environment has the capabilities of flexibly dealing with raster and vector formats, of handling data errors introduced in the integration, and of handling temporal information. This could be accomplished by extending the capabilities of the EA system in the following respects:

- a) *The capability of Entity-like control over remote sensing image components (e.g., themes):* In most image-based systems, locational and attribute queries about image components are difficult to carry out. On the other hand, a high level image analysis approach tends to be based on the predictive description of image objects. These two situations impose a requirement on the higher level integration to achieve the system functionality of entity-like control over remote sensing image components.
- b) *The capability of incorporating EA's data directly into image processing:* This incorporation is also addressed in the first level integration, where data are intended to be transported to the image analysis system. In the second level integration, however, a direct incorporation could be attempted. That is, the image processing system can

directly access the EA's database and use the related spatial data in remotely sensed image processing. Thus, image processing and image mapping conducted in the image analysis system should become more efficient.

- c) *The capability of accommodating (spatially, radiometrically, and temporally) heterogeneous data input in a coherent manner:* Spatially, the system should have the capability to accommodate data with different data structures, different spatial resolutions, and different projections. This is particularly important for higher level image interpretation, since most of the ancillary data are usually obtained from different agencies which may have different standards of spatial representations. Radiometrically, in order to extend the information scope of current national mapping, it is preferable for the system to have certain capabilities to handle the spatial information from sensors which cover various spectral bands. As such, the system should have the basic capability to calibrate the data from different radiometric sensors. Temporally, the system should have the capability to accept temporal spatial and non-spatial data, and the capability to accommodate the potential conflicts resulting from the temporal difference involved in spatial data analysis. This implies that some basic temporal interpolation and extrapolation functions are required.
- d) *The capability of accommodating hierarchical entities.* This capability is important because with it, users can easily view or query spatial information at different detailed levels. It is also important for the efficient hierarchical segmentation of images and for map generalization.
- e) *A spatio-temporal database system capable of handling spatio-temporal geographic information:* As with most existing GIS databases, the current EA database only represents the state of the universe of discourse at a particular instant of time. These

databases face several limitations. For example, it is very difficult to trace historic data of a specific spatial object; this could be of interest in some applications, especially in the dynamic modelling of geographic phenomena. It is therefore necessary to enhance the database capability so that spatio-temporal information from remote sensing images and from other sources can be well organized.

- f) *An integrated data structure for efficiently handling raster and vector data:* Both vector and raster data have their advantages and disadvantages in spatial information analysis. In most cases, they supplement each other (Peuquet, 1984). Low level remote sensing image processing is almost completely oriented to a raster approach, while higher level image analysis and GISs has tended to be vector oriented. An integrated data structure could provide possibilities to assimilate two data structures and enhance remote sensing image analysis and EA applications.
- g) *Data error handling capability, (both positional and attribute errors):* Positional and attribute data errors are inevitably involved in remote sensing image processing (Goodchild and Copal, 1989). Sliver polygons will also be unavoidable when using remotely sensed data to update EA maps. A higher level integration should have the capability of handling these data errors.
- h) *System interface with various remote sensing images:* In order to meet the requirements of national mapping at different scales, it would be preferable to incorporate data from various remote sensing sensors that have different spatial and radiometric resolutions into the EA system. Thus, in addition to an interface with Landsat MSS data provided by the IDRISI system, it is necessary to establish the interfaces with other related remotely sensed data sources, such as NOAA AVHRR, Landsat TM, SPOT HRV, and

EOS. These space sensors provide data with more flexible spatial, temporal and radiometric resolutions for national mapping.

In order to achieve an efficient and effective integration based on these requirements, the image analysis system involved must be capable of running on the same hardware and software environments as the EA system. In consequence, this level of integration can be realized by managing the EA system and a remote sensing system under a central controlling framework. A user interface between the two systems must be established as a bridge to link them together (figure 4.2). In the integrated platform, data will be inputted into the system both from the EA system and from the image processing system. Data manipulated by the remote sensing system will be directed to output devices to generate a graphical display, together with vector features retrieved from the EA system, and can be sent either to the EA or to the image processing system. Statistics, analytical graphics, and 2,3-dimensional images can also be generated by using the image and graphic output routines of the image processing system.

The major challenges for this level of integration are the appropriate designs of an integrated vector-raster data structure, an approach to handling data errors resulting from the integration, and a spatio-temporal model. This level integration is termed the seamless approach.

Figure 4.2 The Framework of the Second Level Integration

4.3 THIRD LEVEL INTEGRATION APPROACH

The first and second level integrations are both based on two separate systems that are complementary to each other but interwoven. The third level integration, however, will be geared towards creating a totally integrated knowledge-based EA system (figure 4.3), which would bring together spatial and temporal statistics, maps, and image data into a single system which could function intelligently. Therefore, it can be termed the knowledge-based approach. The main components of this integration level should include the following major elements:

Figure 4.3 The Structure of the Third Level Integration - Knowledge-Based EA

- a) *An Intelligent Spatio-temporal Data Base system (ISDB):* First of all, the database system should be able to efficiently manage both temporal and atemporal geographic information. Thus, users could easily trace the temporal and atemporal status of geographic phenomena, and efficiently use the information in dynamic modelling. Secondly, the system should have the capability to guide inexperienced users through the efficient use of the database. This implies that the system should provide users with an intelligent user interface and a flexible query language.
- b) *A Knowledge-Based Error Handling Subsystem (KBEHS):* An effective handling of positional and attribute errors involved in GIS databases requires use of artificial intelligence (AI) and expert system technologies (Huang, 1991). GIS data errors (both positional and attribute errors) might be caused by various reasons, such as operational mistakes in data digitizing and data input. Therefore, multi-constraints must be used in order to effectively recognize and thereby to correct GIS errors. The knowledge-based approach can then be used to efficiently incorporate multiple heuristics and constraints into GIS error handling.

- c) *A Knowledge-Based Image Analysis Subsystem (KBIAS) for improving the classification accuracy of remote sensing images:* Previous researches have indicated that remote sensing image interpretation can be substantially improved by using AI and expert system technologies through the incorporation of the heuristic knowledge of the domain experts (Argialas and Harlow, 1990). Such a subsystem would thus be very important for effective integration of remote sensing into the EA system.
- d) *A Knowledge-Based Statistical Analysis Subsystem (KBSAS) for time series statistical analysis and spatial statistical analysis of geographic information:* Statistics are a powerful tool for spatial analysis and time series analysis. It is intended that the EA system will contain a variety of geographic information, including data from physical, environmental, social, cultural, economic and resource geography. The value of the information could be considerably upgraded through the use of the statistical tool (Zhang et al., 1991).
- e) *A Knowledge-Based Map Design Subsystem (KBMDs):* The generation of electronic maps involves cartographic expertise, for example, for the selection of symbols and the combination of colors. A knowledge-based map design subsystem would help users in the creation of quality maps.
- f) *A Knowledge-Based Visualization Subsystem (KBVS) with strong capabilities for dynamic and multi-dimensional information presentations:* Providing users with more realistic representation of temporal and atemporal geographic data is one of the key issues in this level of integration. In this respect, advancements in the fields of computer graphics and visualization have provided powerful techniques for the development of dynamic spatial data representation approaches. This subsystem

should include both visualization functions and knowledge for utilizing the functions, so as to provide users with a powerful map display tool.

These are examples of knowledge-based modules, which could be incorporated into a knowledge -based system. Integration at this level, therefore, should ultimately be the outcome of multiple technologies, such as artificial intelligence, computer graphics, pattern recognition, electronic mapping, and remote sensing.

CHAPTER 5

IMPLEMENTATION OF THE INTEGRATION OF THE EA AND AN IMAGE ANALYSIS SYSTEM

Based on the possible integration avenues previously discussed, this chapter addresses the implementation approach to the current integration task of the EA system and an image analysis system (the IDRISI system). The methodology for the implementation is introduced first. This is followed by detailed discussions of each step involved in the methodology.

5.1 METHODOLOGY FOR THE SYSTEM INTEGRATION

The implementation of the integration of the Electronic Atlas and the IDRISI system includes two parts: the integration of system functionality, and the implementation of the system interface (data exchange format). The design and implementation of both parts are based on the technical capabilities of the two systems, on the goals of the integration, and on considerations of the simplicity of data manipulation. Several steps were followed in order to achieve the integration.

1. *Selecting an appropriate approach for the integration of the EA system and an image processing system (the IDRISI system):* This is the most important step in the integration. This step fundamentally influences the design and implementation of the integration and users' utilization of the systems, since different integration approaches require different software and hardware platforms, and different data exchange procedures.

2. *Designing a data exchange format between the EA and the IDRISI systems:* This is necessary, since the EA and the IDRISI systems operate on different platforms. The exchange of data between these two systems can only be achieved through the use of a common data exchange format.
3. *Defining the contributions of each system to the integration:* Since both the EA and the IDRISI systems are designed and implemented on different platforms and for different applications, the functionalities of each system are not completely applicable to the task of integration. Therefore, it is necessary to define the functionalities of each system in the integrated environment, in order to achieve an efficient integration.
4. *Designing a data exchange procedure for the integration, based on the data exchange format designed in the second step:* A feasible and efficient data exchange procedure can be significantly beneficial for later integration operations. What is required is a procedure by which users can easily incorporate the EA data into the IDRISI system to assist in image processing, or vice versa.
5. *Carrying out a functionality test of the system data exchange:* Both image data from the IDRISI system and thematic data from the EA system were used to test the feasibility of the system data exchange procedure.

5.2 SELECTION OF THE INTEGRATION APPROACH

Two basic factors must be taken into account in the selection of the integration approach. The first factor is the technical capabilities of both the EA and the IDRISI systems, since this will affect the basic configuration of the system implementation and the design of the system interface. On the one hand, the EA system is working under SunOS environment,

and its hardware platform is the SUN workstations. From the viewpoint of the EA operation environment, it is necessary that the integration approach accommodate the basic requirements of SunOS systems and SUN workstations. On the other hand, IDRISI is a PC-based system, i.e., it works in the MS-DOS environment and on IBM compatible platforms. This requires that the integration approach also accommodate the basic requirements of the IDRISI working environment.

The second factor which will affect the functionality design of the integration, is the goals of the integration. The objectives of the integration indicated in Chapter 1, can be summarized into two categories: basic goals and comprehensive goals. The former include the basic capabilities for image manipulation. The latter include three functionalities, namely thematic data extraction from remote sensing image for national mapping, post-processing of classified remote sensing image, and, image mapping. These impose a requirement on the determination of the integration approach, since the data between the two systems should be easily accessed by both systems. Not only can thematic data be sent from the IDRISI system to the EA system for national mapping, but EA maps can be also used to assist image analysis and image mapping in the IDRISI system.

Therefore, in order to achieve an efficient integration between the EA and the IDRISI systems, the integration approach must be able to accommodate both the technical conditions of the two systems and the goals of this task.

There are basically three potential approaches for the integration, namely, as discussed in chapter 4, the parallel approach, the seamless approach, and the knowledge-based approach, corresponding to the first, the second, and the third levels of integration respectively. The last two approaches are not appropriate for the present task, since they require that all functionalities be implemented in the same hardware and software platform, a condition which is not met with the operational environments of the EA and IDRISI

systems. More specifically, the second approach has to be implemented by establishing a common user interface in order to organize and control the operations of both the EA and IDRISI systems. The third approach is more advanced and requires some more advanced functions than a unique development environment, and more than the traditional image analysis and GIS technologies. Several methodologies required for this level of integration, e.g., the intelligent spatio-temporal database design, are still under development, and a long term effort needs to be made in order to achieve such a goal. The first approach, however, is a flexible approach, since the integration following this approach can be implemented under different hardware and software platforms through the establishment of a data exchange format.

Therefore, the first level integration approach, i.e., the parallel approach, is selected for fulfilling the current integration task. The basic configuration for the integration using this approach is shown in figure 5.1.

Figure 5.1 Configuration of the Integration Approach for the EA and IDRISI Systems

5.3 DESIGN OF DATA EXCHANGE FORMAT

When using the parallel approach for the integration, the establishment of the data exchange is the most important task. In order to achieve this, criteria for the data exchange need to be set up.

5.3.1 Design Criteria

There are two basic criteria for the design of a data exchange format between the EA and IDRISI systems. The first one, from a user's perspective, is that the data exchange between the two systems should be as simple as possible. The other, from the technical viewpoint, is that the data exchange format should achieve the sharing of classified image data not only with the EA system, but also with other systems within NAIS. The first criterion suggests that the procedure and data format involved in data exchange through the interface should be easily understood by inexperienced users, so that they can achieve data exchange between two systems without having a detailed understanding of the system structures. The second criterion implies that an investigation of the data formats commonly used in geographic information systems and image analysis systems is needed. As a result, the interface could be one that is simple, able to accommodate both EA and IDRISI data, and capable of providing classified image or thematic data usable for other information systems used within NAIS.

5.3.2 Implementation of the Data Exchange Between EA and IDRISI

According to the criteria of the interface design, the ARC/INFO ungenerated data structure is finally selected as the data exchange format for the integration. This is based on an investigation of the EA data formats and of the commonly accepted data structures in most GISs such as ARC/INFO, SPANS, PAMAP, GRASS, and SYSTEM-9, and most IASs, such as PC, EASE/PACE, DIPIX ARIES, and I²S. This is not only because that the EA system uses ARC/INFO as a data input medium and that most of the current GISs and IASs have an interface with the ARC/INFO system in the ARC ungenerated structure, but also because the ARC ungenerated data structure is easily understood by users.

The data organized in this data structure starts with an identifier of the thematic feature (FID), then follows with the sequential X,Y coordinates of the feature, and ends with a flag identifier (END), i.e.,

FID X₁ Y₁ X₂ Y₂ X_N Y_N END

The structure can also be easily converted to other data structures. Thus, the structure basically meets the criteria of the interface design for the integration, since it is both simple and easy for conversion to other data formats.

5.4 DEFINITION OF THE SYSTEMS' RESPONSIBILITIES

The major criteria for defining the roles of each system in the integration are feasibility and efficiency. Since the EA system is basically a vector-based system and the IDRISI system is a raster-based system, these conditions imply that it is preferable that the basic vector based operations be carried out by the EA system, while the raster-based operations be taken over by the IDRISI system. The functionality needed in the integration should be examined before the definition of system responsibility is made

5.4.1 Functionality Needed in the Integration

The functionalities to be achieved in the integration are presented as follows (detailed discussions dealing with these operations are found in Chapters 6, 7 and 8 respectively):

Basic Functionalities for Image Operations

- Data management, including image expansion, contraction, window, transposition, concatenation, image registration, and image resampling.

- Analytical operations, including paired image overlay, image scalar, reclassification, filtering operation.

Comprehensive Functionalities for Image Operations

- Thematic information extraction, including preprocessing of image data, extraction of signature data, and image classification.
- Image post-processing, including "noise" filtering, format conversion (vector-to-raster and raster-to-vector), spatial resolution standardization, projection conversion, and merging of remote sensing with other data sources.
- Image mapping, including atemporal image mapping, and temporal image mapping.

With these functionalities, remotely sensed images can be integrated into the EA system at the initial level.

5.4.2 The EA's Responsibilities

Based on the functionalities to be achieved in the integration and the capability of the EA system in vector and raster data processing, the following operations will be carried out by the EA system.

- Handling of raster to vector conversion "noise",
- Projection conversion of thematic data,
- Merging of remotely sensed data with other data sources,
- Image mapping capabilities.

Handling of raster to vector conversion "noise" is a typical vector-based operation which is implemented in the EA system. However, in order to facilitate user's operation, particularly in the operation of overlaying remote sensing images with vector data which is extracted from remote sensing data, the function is also provided in the IDRISI environment. Projection conversion of thematic data can be carried out both in raster mode and in vector mode. However, a vector mode implementation of this operation is apparently more efficient than the raster mode, since the raster mode is area-based and the operation has to be carried out on each of the pixels of a whole image. The third operation, namely, the merging of remotely sensed data with other data sources, actually embraces a group of functionalities, which can be either raster-based, or vector-based, or mixed based. In order to provide users with flexible selections, these operations are carried out on both the EA and the IDRISI systems. The last operation, i.e., image mapping, also includes a number of functionalities, which are primarily raster-based operations. However, in order to provide the user with more flexible image mapping environments, these operations are also implemented on the two systems.

5.4.3 The IDRISI's Responsibilities

Most of the functionalities for remote sensing image analysis to be performed in the integration are raster-oriented operations. Since the IDRISI system is a raster based system and since it has provided fundamental functions for image analysis, it would be more practical to implement these functions under the IDRISI environment. These functions include:

- Basic capabilities for the image operations listed in Section 5.4.1 (Functionality Needed in The Integration)
- Capabilities for thematic data extraction

- National coverage image concatenation
- Handling of classification "noise"
- Raster to vector data format conversion
- Spatial resolution standardization
- Functions for image mapping
- Functions for merging remotely sensed data with other data sources.

5.5 DATA EXCHANGE PROCEDURES

Data exchange between the EA and the IDRISI systems is carried out through four steps: data processing, data format conversion, data transformation, and data reorganization. In order to achieve the bi-direction data exchange between the two systems, the procedures are separately implemented in the EA and the IDRISI systems. The whole logical procedure for the data exchange between the two systems is shown in figure 5.2. This section presents detailed discussions of each process.

5.5.1 Data Processing

Data exchange between the EA and the IDRISI systems is achieved through the data exchange format, which is implemented in an ARC/INFO ungenerated data format. However, as discussed in Chapter 3 (Major Environments of the Integration), the EA system at the present time only accepts vector data as input, while the IDRISI system is a raster-based system. Thus, the classified image data in raster format must be converted into vector format before being converted into ARC/INFO format and sent to the EA system. The procedure is included in the I-E-3 operation shown in figure 5.2(a). This operation is carried out by using the IDRISI raster-to-vector conversion function <POLYVEC> in the data entry modules. The reverse conversion, vector-to raster,

(a) LOGICAL DATA EXCHANGE PROCEDURE FROM IDRISI TO EA

(T) -- TRANSFORMATION

(b) LOGICAL DATA EXCHANGE PROCEDURE FROM EA TO IDRISI

(E-I-1) -- OPERATION

Fig. 5.2 The Logical Procedures for the Data Exchange Between The EA and IDRISI Systems

has to be carried out in order to send thematic data from the EA system to the IDRISI system for the purpose of assisting in image analysis and image mapping. This operation, E-I-3 shown in Fig. 5.2 (b), is accomplished by using the IDRISI vector-to-raster conversion function. The IDRISI system provides three basic vector-to-raster conversion functions: raster point data to vector point data <POINTRAS>, raster line data to vector line data <LINERAS>, and raster polygon data to vector polygon data <POLYVEC> in data entry modules. The procedures are shown in figure 5.3.

Figure 5.3 Logical Procedures for Bi-Direction Raster/Vector Format Conversion

5.5.2 Data Format Conversion

After the data is processed, format conversions should be carried out. Since the data exchange between the two systems is based on the data exchange format, namely, the ARC/INFO ungenerated data format, data in both the EA and the IDRISI systems should be converted into ARC/INFO ungenerated format for exchange. The conversion from IDRISI format to ARC/INFO ungenerated format (operation I-E-2 shown in figure 5.2(a)), or from ARC/INFO ungenerated format to IDRISI format (operation E-I-2 in figure 5.2 (b)) is achieved by using the IDRISI function <ARCIDRIS> in peripheral modules. The reverse conversion, from EA format to ARC/INFO ungenerated format (operation E-I-1 in figure 5.2 (b)) is not necessary, since all the EA data are input from the ARC/INFO system

in the National Atlas Information System (NAIS). This implies that the EA data required for the IDRISI application can be directly imported from the ARC/INFO system in the NAIS. Then, the IDRISI function <ARCIDRIS> is used to convert ARC/INFO format data into the IDRISI format data. The procedure is shown in figure 5.4.

Figure 5.4 Logical Procedure for EA and IDRISI Data Format Conversion

5.5.3 Data Transformation

Transformation of ARC/INFO ungenerated format data from the EA system to the IDRISI system, or vice versa (operation T shown in Fig. 5.2) follows the data format conversion. The operation can be achieved in two ways, as shown in figure 5.5. One way is through

Figure 5.5. Data Transformation between the EA and IDRISI Systems

the PC network file system (PC-NFS), which is a data communication package used for PC computers and SUN workstations. The other way is using the SUN-DOS system. Users can transport data in one of these ways, according to their particular situations.

5.5.4 Data Reorganization

The data in ARC/INFO ungenerated format from the EA system can be directly converted to IDRISI format and used for IDRISI applications. However, the data in ARC/INFO ungenerated format, converted from the IDRISI system, must be compiled before being used in EA applications. Namely, it is necessary to create an attribute file and a point/polygon file for each of the data sets, for use by the EA (the operation is included in I-E-1 shown in Fig.5.2 (A)). Afterwards, the EA data input function <LOAD> in data entry modules can be used to organize the data into the EA database system. The whole procedure is shown in figure 5.6.

Figure 5.6 Logical Procedures of the Reorganization of ARC/INFO Ungenerated Data into the EA System

5.6 FUNCTIONALITY TEST

A land use image, provided by the IDRISI accompanying data set, is used for the functionality test of the system integration. The image, as shown in figure 5.7, consists of

about 30 polygons, which include 7 land cover types. First, the image is converted into vector data using the IDRISI function <POLYVEC>. Then, the IDRISI to ARC/INFO conversion operation was carried out for the vector data through the IDRISI function <ARCIDRISI>. Thus, the image data are transformed into the ARC/INFO ungenerated format. Following this, an attribute file and a point file are created for these data. Finally, the data are sent to the EA data base through the EA function <LOAD>.

The test of data exchange between the EA and IDRISI systems showed that the designed approach to the system integration was feasible, and the first level integration could be achieved using this approach.

Figure 5.7 Data Set for the Functionality Test of Data Exchange

CHAPTER 6

THEMATIC INFORMATION EXTRACTION FOR NATIONAL MAPPING

The extraction of national coverage thematic information from remote sensing images is one of the most important tasks in the integration of remote sensing into the EA system. In this chapter, the methodology used for the extraction of information is outlined. This is followed by detailed discussions of each step involved in the extraction. Finally, an experiment is carried out on the basis of the image interpretation methodology discussed (the experiments are presented in Chapter 9-Experiments).

6.1 METHODOLOGY FOR THEMATIC INFORMATION EXTRACTION

Several procedures are involved in the extraction of thematic data from remote sensing images for national mapping purposes.

1. *Preparation of image data and ancillary data:* In this project, the image data is the basis of the thematic data extraction; examples are the NOAA AVHRR images. The ancillary data is used to assist in image classification and in image mapping; land coverage maps and topographic maps (at the same or bigger scale than that of the map to be generated) are two examples of ancillary data.
2. *Data preprocessing:* Some processes need to be carried out on the image data and ancillary data before the extraction of thematic information, since data is usually represented in different formats, or different media, which may not be compatible with

the format and the system involved in this integration. The processing may include image data format conversion, image quality control processing, etc.

3. *Defining the set of ground cover types into which the images are attempted to be segmented:* These are information classes and could be, for example, water, urban regions, cropland, etc.
4. *Choosing representative pixels from each of the desired set of terrain categories:* These pixels are said to form training data. Training sets for each class can be established using site visits, maps, and photographs or even photo-interpretation of a color composite product formed from the image data.
5. *Using the training data to estimate the parameters of the particular classifier algorithm to be used:* These parameters will be either the properties of the probability model being used or the equations that define partitions in the multi-spectral space. The set of parameters for a given class is also called the signature of that class.
6. *Labeling or classifying every pixel in the image into one of the desired ground cover types (information classes) using the trained classifier:* Here the whole image segment of interest is typically classified.
7. *Producing thematic (class) maps or tabular summaries which summarize the results of the classification and producing an accuracy evaluation report of classification result:* A thematic information extraction is thereby accomplished.

6.2 PREPARATION OF IMAGE DATA AND ANCILLARY DATA

6.2.1 Remotely Sensed Images

The major remotely sensed data involved in the integration are regional and national coverage NOAA AVHRR images. For the purpose of testing of the integration, the regional coverage images - Prairie Provinces NOAA AVHRR data with 4 kilometer resolution (band 1, 2, and 4, 1987) - are used for thematic information extraction, while the national coverage image - a NOAA AVHRR image with 10 kilometer resolution which was derived from the above image through resampling operations - is used for continuous-tone image mapping.

6.2.2 Ground Inventory Data and Maps

Ancillary data are collected mainly for assistance in image analysis and image mapping. For example, historical land cover maps can be used to assist in the more precise selection of training areas for estimating the signature data of each terrain category. In order to create a thematic image map, some of the ancillary data, such as political boundaries, is necessary. The basic ancillary data and maps that have been collected in the integration experiment are national and provincial boundary data, river and lake distribution data, coastline data, and census boundary data of the Prairie Provinces.

6.2.3 Historical Classified Images

There are two purposes for applying historical classified image data in the integration. One is to use the data to assist in image classification, as done with the ancillary data described above. For example, the selection of training areas can be based on the distribution of

terrain categories identified on the historical classified images. The other purpose is to use the data for change detection or dynamic phenomena monitoring. The potential applications may include the monitoring of land use changes or the monitoring of the biospheric environment. The data used for the first purpose are a classified NOAA AVHRR image of the Manitoba Provinces.

6.3 PREPROCESSING OF IMAGE DATA

The data preprocessing referred to here is different from the traditional view of this concept. The traditional view of image preprocessing includes the correction of both the radiometric distortion caused by atmospheric and topographic effects, and the geometric distortion caused by the earth's rotation, the earth's curvature, etc. The image preprocessing addressed in the thesis, however, only refers to the operations that need to be carried out after these operations and before signature data extraction, image classification, and image mapping. The processes include data format conversion, image quality control, and image clustering operations. The traditional image preprocessing is not involved in the integration, since the images used for national mapping are assumed to have been preprocessed by the Canada Center for Remote Sensing.

6.3.1 Data Format Conversion

Data format conversion needs to be applied to remote sensing images and to the ancillary data. Firstly, the data from the NOAA AVHRR sensor must be converted into the IDRISI data format, since the IDRISI system does not provide the interface with NOAA AVHRR data. Secondly, the ancillary data, such as national and provincial boundary data, river and lake distribution data, coastline data, and census boundary data, must also be converted into a format compatible with the IDRISI system. The conversion operations of both the

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NOAA AVHRR images and the ancillary data are carried out by using the function <EXCONVER> developed at the Canada Center for Remote Sensing. This function has been included in the IDRISI system as part of its functionalities.

6.3.2 Image Quality Control

Images involved in the integration are often acquired at different times and in different space orbits. The variation in atmospheric and sensor conditions may cause variation in grey level distribution of the same type of land covers on different images (even with the same physical conditions). This variation may result in perceptive mistakes in the continuous-tone image maps. It is therefore necessary to carry out a grey level equilibrium operation on the images involved.

The following procedures for the operation of image quality control are usually carried out for the integration:

[PROCEDURE-6.1]:

1. *Geometrically registering adjacent images to each other.* This can be done in several steps.
 - a) Preparing basic reference topographic maps of interest areas. The maps can be of either the same scale as or larger than that of the remote sensing images used. The latter is preferred in order to achieve higher geometrical accuracy in image projection.
 - b) Identifying distinct ground points, so-called Ground Control Points (GCPs), on remote sensing images and their corresponding points on the reference topographical maps,

then recording both their image coordinates and map coordinates. These can be achieved by using the on-screen digitizing and query functions provided by the IDRISI system (both the functions are included in the <COLOR> operation in the image display modules).

- c) Projecting all the images involved onto the reference map projection. The operation can be achieved by IDRISI's resample function <RESAMPLE> in the data management module. The operation provides three types of polynomial functions for users to select, namely, the linear polynomial function, the quadratic polynomial function, and the cubic polynomial function. For a linear fit, a minimum of 3 GCPs is required, while the quadratic and cubic fit minimally need 6 and 10 GCPs respectively.

2. *Applying contrast stretching to all the pixels in the areas of overlap, and producing a uniform appearance throughout the mosaic:* This can be achieved through the following procedures:

- a) Making grey level statistics or a histogram of the pixels on the overlap areas of adjacent images. This statistic can be created by using IDRISI's histogram statistic function <HISTO> in the image display modules. Suppose that the histograms of the overlap area of two adjacent images (figure 6.1 (a)) are the cases shown in figure 6.1 (b) and (c). User needs to recognize the low bound shift "shift-l" and upper bound shift "shift-u" shown in figure 6.1 (c). The shifts will then be used in image contrast stretching processing.
- b) Making contrast stretching on all the images, but using different lower and upper bound numbers. For example, suppose that (LA, UA) and (LB, UB) are recognized as the lower bound and upper bound of image-A and image-B respectively. If (LA, UA) are

used in contrast stretching for image-A, then (LB+"shift-l", UB+"shift-u") should be used for image-B in contrast stretching. Image contrast stretching can be achieved by using IDRISI's image stretching function <STRETCH> in the image display modules.

Figure 6.1 Example of Histograms of Overlap Area of Two Adjacent Images

6.3.3 Image Clustering Processing

The maximum likelihood (MLH) classifier is the most popularly used image classification approach. However, unimodal spectral distributions of image objects are the basic requirement for the effective use of the MLH approach. If a class happens to be multimodal, and this is not resolved, then the MLH approach cannot be effective. The image clustering processing is intended to solve multimodal spectral class problems of image objects, based on a representing subset of the image data. Clustering processing performs the valuable function of identifying the existence of all spectral classes, but it is not expected to perform the entire classification. Therefore, in order to improve the thematic information extraction for national mapping, this approach should be used as a preprocessing approach for remote sensing data.

This operation was achieved through the use of the IDRISI function <CLUSTER> in image processing module. The composite image was created through the use of the IDRISI function <COMPOSITE> in the image processing module.

6.4 TRAINING AREA SELECTION

6.4.1 Considerations of Land Coverages to Be Extracted

The procedures for thematic information extraction presented here are only used to demonstrate the IDRISI system capability for this task. Therefore, only three basic types of land categories have been considered for extraction from NOAA AVHRR images. These three categories include vegetation coverage, agricultural cropland, and water bodies.

6.4.2 Selecting Training Areas for Each Land Category

Sufficient training samples for each terrain category must be available to allow reasonable estimates of the elements of the mean vector and the covariance matrix required for later supervise image classification. For an N dimensional multi-spectral space, at least $N+1$ samples are required to avoid the covariance matrix from being singular. Apart from this consideration, it is important to have as many training pixels as possible, particularly as the dimensionality of the pixel vector space increases, since in higher dimensional spaces there is an increased chance of having some individual dimensions poorly represented. Swain and Davis (1978) recommended, as a practical minimum, that $10 \times N$ samples per spectral class be obtained for training, with $100 \times N$ as being highly desirable if it can be attained.

The selection of training areas is usually achieved by using the historical inventory data, air photographs, or previously classified remote sensing images of the areas of interest. In the

integration experiment, the previously classified remote sensing image of the Prairie Provinces of Canada was used for this purpose. For each of the three categories, about 7 training areas were selected. The results are shown in image 1.

6.5 EXTRACTION OF SIGNATURE DATA

Following the selection of training areas, the extraction of signature data for image classification is conducted. Since three different supervised image classification approaches are involved in the integration, i.e., the maximum likelihood approach, the minimum distance approach, and the parallelepiped approach, the basic elements of signature data which need to be extracted include the mean value of each land category, the covariance matrix of all bands of images involved, and the minimum and maximum values of each land category in each band of image data.

The basic procedures involved in the extraction of signature data are:

[PROCEDURE-6.2]:

1. *Defining training site polygons:* This can be achieved through the use of the on-screen digitizing function provided in function <COLOR> in the data display module of the IDRISI system. Each of the training areas should be indicated by an integer code (the IDRISI system only allows 256 different categories). If more than one training area is used for a single terrain category, then the same identifier must be used for all polygons of the same terrain category. The training area polygons can be either in vector format or in raster format.
2. *Creating signature data from the information contained in remote sensing images for specific training site polygons:* This can be carried out by using the IDRISI function

IMAGE 1 LOCATIONS OF TRAINING AREAS OF THREE LANDCOVERS

<MAKESIG>. In this operation, users need to specify the name of the vector file containing the training site delineations, and the image bands from which the characterization will be undertaken.

The results of the related signature data for three types of basic land categories are shown in Table 3.

Table 3 The Signature Data for Three Types of Basic Land Categories

	Min.	Max.	Mean	Stand Deviation
Water/Snow Category				
Band 1	73	255	190	76.4
Band NDVI	86	203	142	27.1
Band 4	85	202	141	27.1
Cropland Category				
Band 1	78	147	107	9.3
Band NDVI	51	120	81	8.6
Band 4	50	119	80	8.6
Vegetation Category				
Band 1	67	169	82	8.4
Band NDVI	68	139	93	8.7
Band 4	67	138	93	8.7

Figure 6.2 Grey Level Distributions of Three Landcover types in the NDVI Band

As shown in figure 6.2, the grey level distributions of the three land covers in the NDVI band (the cases are similar in other bands) are seriously overlaid. The situation will cause misclassification in the later classification, especially for the classification based on the Minimum Distance and Parallelepiped approaches.

6.6 IMAGE CLASSIFICATION

Basically, there are two types of image classification methodologies which are widely used in thematic information extraction from remotely sensed images. One is based only on spectral information of terrain coverages reflected on the remote sensing images. General supervised and unsupervised approaches are found along this line. The other is based on both the spectral and non-spectral information, i.e., the image data and ancillary data are both used in the image classification.

In the first level of integration, the unsupervised approach, i.e., image clustering (discussed in Section 6.3.3, Image Cluster Processing), is used as a preprocessing for the integration, while the supervised classification approach is used as the primary methodology for the image classification. Nevertheless, the ancillary information approach is recommended for higher level of integrations. The reason for this is that the ancillary information approach, though producing better classification results than the other methods, requires that the image analysis system have supportive functions. The example is the function to use historical spatial data to segment remote sensing images for classification (this function is not currently present in the IDRISI system). But an alternative approach for conducting the operation is proposed in Section 6.6.3, Ancillary Information Image Classification.

The supervised classification approaches are described in this section. The ancillary information approach is also introduced, because of its effectiveness and potential in the higher level integration of remote sensing into the EA system.

6.6.1 Supervised Image Classification Methodologies

Three widely used supervised image classification approaches are the maximum likelihood approach, the minimum distance approach and the parallelepiped approach. Image classifications based on the maximum likelihood, minimum distance and parallelepiped approaches can be achieved by using the IDRISI's function <MAXLIKE> <MINDIST> and <PIPED>.

When using the <MAXLIKE> function, users are first asked for the number of signatures to be used, the name and title of the output file. The system will then indicate that the procedure allows for the incorporation of "a priori" knowledge of the probabilities that any pixel belongs to a given class, i.e. $p(\omega_i)$. If there is no prior knowledge of these probabilities, the users can assume that all classes are equally likely.

In the operation context of the <MINDIST> function, the users need to specify the number of signatures to be used, the name and title of the input and output file. They need then specify whether distance should be calculated as a raw Dn value (the image cell values as they are normally acquired) or as normalized values (standard deviation units), finally indicate the maximum distance allowable for any classification.

In conducting parallelepiped image classification by using the <PIPED> function, the user will be asked for the number of signatures to be used followed by their names. All signatures used must refer to the same set of image bands. The operation will produce an image with cells assigned a class code equal to the signature position in the signature list

and a legend that lists the signatures by name. All of these three approaches have been used in the project for the image classification, and the classification results are presented in Chapter 9, Experiments.

6.6.2 Operational Comparison of Supervised Image Classification Approaches

The selection of the supervised image classification approaches should be made based on the availability of the training data, the spectral characteristics of remotely sensed data involved, and on consideration of image processing efficiency in specific applications. Therefore, an operational comparison needs to be done based on the above three aspects.

Of the three approaches described above, the parallelepiped approach is the fastest one in operational efficiency, since only comparison of the spectral components of a pixel with the spectral dimensions of the parallelepipeds are required. However, the classifier usually produces the poorest results (because of the drawbacks previously discussed). Thus, this approach is only suitable where only a few training data are available, and each of the land covers has a distinct spectral reflectance which is significantly different from others on the remote sensing image.

The computational efficiency of the minimum distance classification is higher than that of the maximum likelihood approach. Although it has a lower efficiency than the parallelepiped approach, the minimum distance approach would not lead to results where some pixels are not classified. However, since covariance data is not used in this technique, and class models are symmetric in the spectral domain, elongated classes can not be well modelled. This characteristic causes the classifier to be less flexible than the maximum likelihood classifier. Nevertheless, this approach is flexible in terms of

requirements for the selection of the training samples of each class. Therefore, it is suitable when the number of training samples per class is limited.

The maximum likelihood approach, compared to the parallelepiped approach and the minimum distance approach, is much more effective and flexible in that each class is modelled by a multi-variate normal class model that can account for spread of data in particular spectral directions. It could result in the best classification if adequate training samples of each class are available. However, the computational efficiency of this approach is among the lowest. It is significant to note that classification time, and thus cost, increases dramatically with increases in the number of spectral components. In consequence, it is recommended that this approach be selected where adequate training data and computational resources are available in the processing of thematic information extraction for the EA system.

In the integration experiment, the three approaches were used. The results from each classifier are presented in Chapter 9 (Experiments).

6.6.3 Ancillary Information Image Classification

The supervised classification is, essentially, a type of straightforward image classification, which only involves spectral information of ground cover types. However, because of the complexity involved in the spectral reflectance of terrain categories, the similarity of different terrain categories in spectral space may cause these terrain categories to be inseparable in image classification. In consequence, the image classification accuracy using the traditional supervised classification approaches are not completely satisfactory for national mapping in a long-term strategy of integration. Therefore, more efficient and effective approaches are needed to improve the classification results.

The ancillary information image classification approach is one of the more effective methods devised in the attempts to improve classifications. Every land cover can be said to be the result of the interaction and inter-constraint of several natural conditions. For example, the growth of a specific crop must follow several physical environmental requirements, such as soil type, soil depth, soil PH value, slope and aspect of land surface, soil temperature, drainage condition, precipitation, and length of the growing season. This implies that the crop image classification can be improved if the above related ancillary information and the inter-constraint knowledge depicting their relationships are incorporated into the crop image classification. The basic framework for achieving this type of classification is shown in figure 6.3. Some of the gains achieved clearly demonstrate that the image classification accuracy can, geometrically and spectrally, be distinctly improved when ancillary information on the related factors are incorporated, along with spectral information, into image classification (Janssen et al., 1990; Skidmore, 1989; Franklin et al., 1986). For instance, Janssen et al (1990) incorporated topographic data from a GIS into land-cover type classification. Their experiments in two agricultural

Figure 6.3 Conceptual Framework of Ancillary Information Image Classification

regions in the Netherlands have shown that the accuracy of land-cover classification were improved by 12 percent and 20 percent respectively. Skidmore (1989) used an expert system which incorporated DEM data and TM images to classify eucalypt forest in Australia; his results shown that the accuracy of classification was improved by over 10 percent.

A straightforward way to classify remote sensing images with ancillary data is to form extended pixel vectors that contains both the spectral and non-spectral data, and directly incorporate the extended pixel vectors in image classification. For example, DEM, slope, and aspect data of areas of interest can be used as three extra channels in forest image classification. Problems with such an approach include incompatible statistics of the disparity data types, the need to have larger training data sets, and, when using maximum likelihood classification, the quadratic cost increase of image classification processing with dimensionality. Alternative schemes for classifying remote sensing images with ancillary information include deriving sets of prior probabilities from non-spectral data, which are then used in equation (6.6.2) (Strahler, 1980). The method discussed above can be called "non-knowledge-based" ancillary data approach.

In the IDRISI environment, the "non-knowledge-based" ancillary data approach can be achieved through the use of the following procedures.

[PROCEDURE-6.3]:

- 1) *Projection conversion*: It is necessary if the projection of ancillary data is different from the one used in image classification.

- 2) *File format conversion:* It is necessary to convert related ancillary data file into the IDRISI file format if the format of ancillary data is different from the IDRISI format.
- 3) *Vector-to-raster formation conversion:* This operation should be carried out if related ancillary data are organized in vector format using the same spatial resolution as the remote sensing to be classified.
- 4) *Resolution standardization:* This must be carried out if the ancillary data are organized in raster format with a spatial resolution different from the one used for remotely sensed data to be classified.
- 5) *Image classification:* This can be carried out through the use of the procedures presented in the above sections. In the image classification operation, ancillary data are considered as extra image channels.

However, a higher level image classification utilizes whatever domain specific knowledge is available about the image objects. Advancements in the fields of artificial intelligence and knowledge-based expert systems have provided powerful methodologies for the development of computer programs that have the potential to represent domain knowledge and expertise in image classification (Argialas and Harlow, 1990). In recent years, the knowledge-based approaches have been widely used in image interpretations, as different as land cover analysis, such as forest clear-cut monitoring and vegetation change detection (Goldberg et al., 1985; Goodenough et al., 1987; Civco, 1989), map-assisted photo-interpretation (Nicolin and Gabler, 1987), image segmentation (Levine and Shaheen, 1981), hyper-spectral image analysis (Nago and Matsuyama, 1980), cartographic feature extraction (McKeown et al., 1985; Schenk and Ziberstein, 1990), analysis of geological structures (Chiou, 1985), and, structural analysis of complex aerial photographs (Argialas and Narasimhan, 1988; Mintzer, 1989).

The knowledge-based image classification approach has several advantages over traditional image classification approaches. For instance, the heuristic knowledge about the distributions of spatial objects, and about the spatial and temporal relationships between each land category to be extracted can be effectively incorporated into image classification. Example of heuristic knowledge is crop rotation knowledge which presents temporal relationship of crop growth. Research (Huang and Zhang, 1991b) on incorporating crop rotation knowledge into crop type classification of synthetic aperture radar (SAR) images shown that the classification accuracy can be improved by 10 percent for both CVV (C band vertically polarized energy transmitting and vertically polarized echo receiving) and CHH (C band horizontally polarized energy transmitting and horizontally polarized echo receiving) channels.

The flexibility, power, and effectiveness of combining artificial intelligence, pattern recognition, and image analysis techniques have been demonstrated with research prototypes already built (detailed reviews on the characteristics of each related expert system listed above are given by Argialas and Harlow, 1990, and Fabbri et al., 1988). However, the knowledge-based approach is not directly used in this level of the integration of remote sensing into the EA system since it is an application-oriented approach and it requires exhaustive investigations on knowledge acquisition of specific application. But, rather, the approach is recommended for the third level integration,

6.7 ASSESSMENT OF THE CLASSIFICATION RESULTS

At the completion of an image classification, it is necessary to assess the accuracy of the results obtained. This will allow a degree of confidence to be attached to those results and will serve to indicate whether the analysis objectives have been achieved.

Accuracy is determined empirically by selecting a sample of pixels from a thematic map and checking their labels against classes determined from the reference data (preferably gathered during site visits). Reference data is often referred to as ground truth. From these checks, the percentage of pixels from each class in the image labeled correctly by a classifier can be estimated, along with the proportions of pixels from each class erroneously labeled into every other class. These results are then expressed in tabular form, often referred to as a confusion matrix.

The choice of the sample of pixels for accuracy assessment is an important consideration, and is still subject to investigation (Richards, 1986). The simplest strategy for evaluating classifier performance is to choose a set of testing fields for each class, these being akin to training fields used to estimate class signatures. These testing fields are labeled using available reference data, presumably at the same time as the training areas. After classification, the accuracy of the classifier is determined from its performance on the test pixels. Another approach, with perhaps more statistical significance, since it avoids correlated near-neighbouring pixels, is to choose a random sample of individual pixels across a thematic map for comparison with reference data. However, in order to avoid the potential area-weighted problem with the random sampling approach (i.e., the larger classes tend to be represented by a larger number of sample points than the smaller classes), an approach called stratified random sampling, Richards, 1986, is used in the project. Using this approach, users first decide upon a set of strata into which the image is to be divided. Random sampling is then carried out within each stratum. The strata could be any convenient area segmentation of the thematic map, such as grid cells. However, the most appropriate stratification to use is the actual thematic classes themselves. Consequently, a random sample within each thematic class should be chosen, in order to assess the classification accuracy of that class.

Even though there is no general guideline on the percentage of samples that have to be chosen for the assessment of classification results, adequate samples must be taken, so as to ensure that the assessment results entered into the confusion matrix are an accurate reflection of the performance of the classifier.

For the conducting of assessment in the current environment, the following basic procedures are used:

[PROCEDURE-6.4]:

1. *Preparing the basic reference data needed for accuracy assessment:* It is preferable to use the same data as those used for training samples. In the project, the classified NOAA AVHRR image of the Prairie Provinces was used.
2. *Deciding upon a set of strata, and using them to segment the image to be assessed:* The recommended stratification is to use the actual thematic classes in the classified image.
3. *Carrying out random sampling on each of the strata:* This can be achieved by using the on-screen query function of the IDRISI system. The function is organized in the function <COLOR> in the display modules.
4. *Comparing the results from the classified images with the reference data, and listing all the test results in form of confusion matrix.* From the comparison of image classified results with reference data, the percentage of pixels from each class of pixels in the image labeled correctly by the classifier can be estimated, along with the proportions of

pixels from each class erroneously labeled into every other class. These results are then expressed in tabular form which is often referred to as a confusion matrix.

CHAPTER 7

IMAGE POST-PROCESSING

Image post-processing is one of the major tasks in the integration. It is a challenging issue because a series of operations, dependent on the characteristics of the remote sensing images, need to be done in order to create quality maps for national mapping. This chapter first discusses the necessity of post-processing. Then, the methodology for formulating the processing is presented. Finally, various operations for post-processing are introduced and practical procedures are provided.

7.1 THE NECESSITY OF IMAGE POST-PROCESSING

The integration of remote sensing into GIS can be conceptualized as a flow in which geographic data after a series of transformations becomes geographic information; this flow is shown in figure 7.1. This diagram shows that there is a distinct procedure, image post-processing, located between thematic feature extraction and geographic databases.

Figure 7.1 Data Flow in the Integration of Remote Sensing into GIS

The need for image post-processing arises from the gap in viewpoint between GIS operators and the remote sensing specialists. GIS operators regard the accurate, digital, polygonal, point, or network data sets to be the raw data, which forms the starting point for subsequent work. To the remote sensing specialist, on the other hand, the digital remote sensing scene represents the raw data and the classified image data, expressed in polygons or other forms, is considered to be the highly processed product. Thus, depending on the point of view, one's highly processed output data can be another's raw input.

This gap must be narrowed in order to achieve an effective integration of remote sensing into the EA system. More specifically, before classified remotely sensed data is sent to the EA system, the image post-processing from the standpoint of remote sensing, or data preprocessing from the standpoint of the GIS domain, is required.

7.2 METHODOLOGY FOR FORMULATING IMAGE POST-PROCESSING OPERATIONS

Several operations are needed for image post-processing in the integration of remote sensing into the EA. These operations were formulated through several steps:

1. *Analyzing the difference in characteristics between spatial data for national mapping and remote sensing images to be used in the integration:* This analysis of differences provides a basis for the design of the operations needed for image post-processing.
2. *Formulating basic image post-processing operations for the integration:* These operations are conducted to resolve the differences identified in the first step.
3. *Formulating ways to implement these operations in the integration environment:* It is proposed that the image post-processing be carried out in the IDRISI system that

emphasizes image processing. Therefore, the focus is to find the functions required by the operations and available in the system.

4. Developing functions which are necessary for image post-processing but not available in IDRISI: The functions, such as image classification "noise" and island polygon handling, that are required but not found in the IDRISI system must be developed in the integration project.

5. Testing the functionality of the image post-processing operations: A set of remotely sensed data was used to test and evaluate the effectiveness of the post-processing operations, in order to validate the design, as well as the implementation.

6. Formulating operational procedures for image post-processing: This was to provide general operational procedures for use in later integration operations.

7.3 OPERATIONS OF IMAGE POST-PROCESSING

Several operations are included in image post-processing, in an attempt to effectively integrate remote sensing images into the EA system. They are format conversion, "noise" filtering, image concatenation, spatial resolution standardization, projection conversion, multi-temporal image matching, and the merging of remotely sensed data with data from other sources.

7.3.1 Format Conversion

The basic difference between cartographic data in databases for national mapping and remote sensing image data is that they represent information about the world using different concepts of space, which might be called "object-based" and "field-based". Cartographic data in databases usually fills an "empty" Euclidean two-dimensional space with objects

(e.g., transportation features, houses, lots), namely, a vector representation; whereas remote sensing separates a non-empty space into a tiling of raster elements (pixels), i.e., a raster representation. In particular, the EA system at the present time only accepts vector format data. Consequently, the first requirement for remotely sensed data used in national mapping is the conversion of raster format data into vector format data (national coverage image mapping where raster mode is preferable).

The data format conversion is achieved, in the integration, through the use of IDRISI's raster-to-vector function <POLYVEC> in the data entry modules. In the operation of this function, users need to indicate the logic to be used for the vector file coordinates. Choices include: (1) matching coordinates to the row/column structure of the input image, (2) entering the coordinates of the corner points from the keyboard, or, (3) adopting the coordinate range from an existing vector file. Also, users need to indicate if they wish to process only the polygons listed in a value file. This is a convenient way to extract and convert the polygons from an image file that may also contain points and lines (details are presented in IDRISI's user manual). In addition, users are required to indicate whether there is a background polygon that should not be processed.

Because of the inability of the EA system to handle island map objects, the thematic data in vector format, which are directly vectorized from classified remote sensing images can not be sent into the EA system. Thus, a layered vectorization strategy is proposed in raster-to-vector conversion of classified remote sensing data, to ensure that there is no island polygon in each thematic layer of vector format remote sensing images. The basic principle of this strategy is to vectorize the thematic data of classified remote sensing images each landcover type-by-each landcover type. The layered vectorization strategy can be achieved through the use of value files, in which users must create a value file for each thematic layer to be converted. The value file contains two columns of integer data, in which a list of

thematic identifiers is organized in the left column along with a list of their topologic dimension in the right column. Points have a topologic dimension of 0; lines are indicated by 1 and polygons by 2. Through the use of the IDRISI <POLYVEC> function, users will be asked for the value file if they carry out a layered vectorization operation. This is followed by an island polygons processing, in which the function <ISLAND> developed for the integration must be carried out.

The data set used for the experiment of raster-to-vector format conversion is classified remote sensing image of the Prairie Provinces of Canada. Both experimental data set and results are presented in Chapter 9 (Experiments).

7.3.2 "Noise" Filtering

The second difference between cartographic data used for national mapping and remotely sensed data is that the former are usually highly generalized information, whereas the latter are a more objective reflection of ground. This difference implies that some of the image objects or polygons in classified images might be considered as "noise", called classification "noise" (as shown in figure 7.2 (a) (b)), in cartographic production standard. Examples are the image objects with few pixels or with areas which are smaller than the basic threshold of map objects used for national mapping. Another type of noise involved in the integration is one resulting from the raster to vector format conversion, called conversion "noise", as shown in figure 7.2 (c). This type of noise is the consequence of the saw-shape effect existing in the vector format of remote sensing data. The handling of these "noises" is required when sending the thematic data extracted from remote sensing images to the EA system for national mapping applications. The mechanism for handling

(a)

Raster-To-Vector Format Conversion "Noise"

(b)

Figure 7.2 Classification "Noise" and Format Conversion "Noise" of Remote Sensing Data

the image classification "noise" was taken over by the function <EXNOISE> developed in the integration. It is now accomplished in vector mode, considering the operational efficiency. Handling of the classification "noise" in the program is based on the concept of the area threshold. If the area of any single image object (see figure 7.2 (a)) is smaller than a defined area threshold for the smallest map element, then the image object has to be filtered. In this operation, users need to specify the threshold (pixel number or area) of image objects that are considered as "noise". The data set used for the test of the functionality and the processed results are presented in Chapter 9 (Experiments).

The mechanism for handling conversion "noise" can be achieved in the integration in both the EA and the IDRISI systems. In the EA environment, the operation can be carried out through the use of the ARC/INFO line generalization function. The function is based on the Douglas-Peucker generalization algorithm (Douglas and Peucker, 1973).

In the IDRISI environment, the line generalization function <LINEGEN> can be used for this purpose. The function <LINEGEN> provides three algorithms for line generalization, namely, the Douglas-Peucker algorithm, the point selection algorithm and the low pass filtering algorithm. In the operation of the above three approaches, users need to provide: (a) the size of tolerance to be used, (b) the point selection rate to skip, and (c) the number of average moving point respectively.

The data set used for this functionality test, as well as the processed results, are presented in Chapter 9 (Experiments).

7.3.3 National Coverage Image Concatenation

For a national coverage image map of Canada, about six NOAA AVHRR images are needed. These images must be concatenated before being applied to national mapping, since spatial data used for national mapping are required to be organized in national coverage, rather than as separated spread sheets. The methodology for image concatenation varies with two types of image mapping, namely, continuous-tone image mapping and classified image mapping.

For continuous-tone image mapping, the concatenation procedures are:

[PROCEDURE-7.1]:

1. *Projection conversion and image quality control*: The operations are the same as those presented in PROCEDURE-6.1 in Section 6.3.2 (Image Quality Control).
2. *Concatenating all these images into a national coverage mosaic*: Based on the results from the first step, the following procedures are used to eliminate the duplicate pixels within the areas of overlap on each pair of adjacent images:
 - a) Recognize the distinct patterns in overlap areas of adjacent images through visual interpretations.
 - b) Using IDRISI's on-screen query function to extract common boundaries.
 - c) Using IDRISI's window function <WINDOW>, in the data management modules, to extract the other parts of the images, except the common pixels for adjacent images.
 - d) Using IDRISI's image concatenation function <CONCAT>, in the data management modules, to merge all the adjacent images together. This function provides users with the capability to concatenate new sections on either the top, bottom, left, or right sides of a base image.

These procedures are shown in figure 7.3 (a).

For classified image mapping, the major difference between image concatenation and continuous image maps lies in the phase: grey level equilibrium. In classified image mapping, this step is replaced by a standard image classification procedure (see Section 6.6 (Image Classification)). Figure 7.3 (b) shows the basic procedures.

Figure 7.3 Image Concatenation Procedures for Continuous-Tone and Classified Image Mapping

7.3.4 Spatial Resolution Standardization

For raster mode image mapping, there is a problem with the spatial resolution of remote sensing data. As indicated in Chapter 3 (Major Software and Hardware Environments of the Integration), the basic scales used in national electronic image mapping are 1:2 million and 1:7.5 million. This indicates that, in the EA environment, the resolution of each pixel for the above two scale images are 500 m and 1875 m, which are different from that of NOAA AVHRR images with 1 kilometer resolution provided by the Canada Center for Remote Sensing. This difference must be resolved in image post-processing.

This operation is carried out in the integration by using IDRISI's image expansion function <EXPAND> and reduction function <CONTRACT> in the data management modules. When operating these functions, users will be asked for an expansion or reduction factor.

7.3.5 Projection Conversion

The difference in map projection between the EA maps and the remote sensing images used for national mapping must be resolved. The basic map projection used in national mapping, in Canada, is the Lambert Conformal Conical projection, whereas most remotely sensed data are represented in the UTM projection. The projection conversion operation has been achieved in the integration by using IDRISI's resampling function <RESAMPLE> in the data management modules. The basic procedures are the same as those presented in PROCEDURE-6.1 in Section 6.3.2 (Image Quality Control).

7.3.6 Multi-temporal Image Matching

Correct extraction of information dealing with change is one of the basic requirements for dynamic phenomena monitoring, temporal image mapping, and data updating. In order to correctly and effectively extract change information from remote sensing data, precise matching of multi-temporal images must be carried out. In the current integrated environment, this is accomplished by using related functions provided by the IDRISI system. The basic procedures are:

[PROCEDURE-7.2]:

1. *Projection conversion of all related temporal images:* The detailed procedures involved here are presented in PROCEDURE-6.1 in Section 6.3.2 (Image Quality Control).
2. *Visually recognizing and extracting the overlap areas shared by these images:* This operation is similar to that presented in PROCEDURE-7.1 (2) in Section 7.3.3

(National Coverage Image Concatenation). The only difference is that in this operation, IDRISI's <WINDOW> function is used to extract the common areas rather than to extract the non-common areas done in the image concatenation operation.

3. *Matching all these images and extracting the change information of interest:* This is carried out by using IDRISI's overlay and subtraction function <OVERLAY> in the analytical modules.

The full procedures are shown in figure 7.4.

7.3.7 Superimposing Remotely sensed data with Data from Other Data Sources

National coverage synthetic image mapping is one of the major objectives of the integration. This implies that the spatial data from remote sensing images needs to be merged with data from other data sources. The fundamental requirement for this operation is that all the data involved must be precisely matched. This objective can be achieved in three ways. Namely, the data can be merged in raster format, in vector format, or in mixed format. Based on the functionalities of the IDRISI and the EA systems, the operation, in the integration, is carried out in both the raster format and the mixed format.

The procedures of the raster mode operation include:

[PROCEDURE-7.3]:

1. *Precisely matching all related images with each other:* The detailed procedures are those presented in PROCEDURE-7.2 in Section 7.3.6 (Multi-temporal Image Matching).

Figure 7.4 Procedures For Multi-temporal Image Matching

2. *Superimposing all of related spatial data:* The operation is achieved by using IDRISI's overlay function <OVERLAY>. This operation is an arithmetical operation, and will therefore lead to a change in the feature codes related to all the images involved. The operation has some negative effects on spatial information merging. Typical examples are that some linear features, such as transportation networks, might be submerged. Therefore, in order to emphasize some specific spatial features, it is necessary to reclassify the image. The reclassification operation is carried out, in the integration, by using IDRISI's <RECLASS> function in the analytical modules.

The difference between the mixed mode operation and the raster mode operation exists in the second step described above, namely, merging of all related spatial data. This step in the mixed mode operation is carried out by using IDRISI's raster and vector data overlay function, provided in the <COLOR> operation in the image display modules. The operation begins with displaying a remote sensing image as a background using the <COLOR> function, then overlays it with a vector data layer after users have entered a "V", input the name of the vector file to be overlaid and color code used for each vector layer data. Theoretically, any number of vector files may be overlaid onto an image.

The procedures for both of the merging modes are shown in figure 7.5.

Figure 7.5 Procedures for Superimposing Remote Sensing Images
with Data from Other Sources

CHAPTER 8

IMAGE MAPPING

The objective of implementing image mapping capabilities in the integration of remote sensing into the EA system is to provide the national mapping of Canada with diverse spatial information presentations. A large family of image maps can be produced in the project. In terms of temporal characteristics, image maps can be grouped into two categories: the temporal image maps and the atemporal image maps. These maps can be further differentiated as continuous-tone image maps and classified image maps. In addition to the 2-dimensional maps generally used, 3-dimensional national coverage image maps can also be created, supplemented with national coverage DEM data. In the current experiments, a variety of image maps were produced, which include: 2- and 3-dimensional remote sensing image maps, 2- and 3-dimensional topographic image maps, 3-dimensional statistical image maps, snapshot temporal image maps, and the overlaid temporal image map. This chapter addresses the methodologies for making these maps. For the convenience of discussions, the experimental data set as well as the result of the experiment are presented in Chapter 9 (Experiments).

8.1 ATEMPORAL IMAGE MAPPING

8.1.1 2-Dimensional Remote Sensing Image Mapping

Two-dimensional image mapping is the most commonly used remote sensing image mapping approach. Basically, there are four different types of 2-D image maps, i.e.,

synthetic and non-synthetic continuous-tone image maps, and, synthetic and non-synthetic classified image maps.

Non-synthetic Continuous-tone Image Maps

A non-synthetic continuous-tone image map is usually created from preprocessed remote sensing data, i.e., the images which are geometrically and radiometrically corrected. The basic requirements of this type of image maps are that they should have the same map projection and a spatial resolution as that used in the national mapping program. In most cases, radiometric enhancement operations, such as contrast modification, histogram equalization, histogram matching or density slicing, are required in order to improve visual effectiveness of images in applications. For creating a national coverage non-synthetic image map, the following procedures are needed (see figure 8.1 (a)):

[PROCEDURE-8.1]:

- 1) *Projection conversion:* Detail refers to PROCEDURE-6.1 in Section 6.3.2, Image Quality Control.
- 2) *Conducting spatial resolution conversion, if the resolution of remotely sensed data is not compatible with the national mapping scales:* Detail refers to the procedures presented in Section 7.3.4, Spatial Resolution Standardization.
- 3) *Performing radiometric enhancement in order to improve visual effectiveness of image maps:* the IDRISI linear contrast strength function <STRETCH> can be used for this purpose. In the operation, the user needs to provide the upper and lower bounds of the stretch and the number of levels required.

Synthetic Continuous-Tone Image Maps

The synthetic continuous-tone image maps are continuous-tone image maps with overlays of other thematic spatial or non-spatial information. Thus, this type of image maps can be created based on non-synthetic continuous-tone image map. For this type of image mapping, the following operations should be carried out (figure 8.1 (b)), in addition to using the procedures presented for the non-synthetic continuous-tone image mapping :

Figure 8.1 Procedures for The Creation of Non-Synthetic (a) and Synthetic (b)

Continuous-Tone Image Maps on IDRISI

[PROCEDURE-8.2]:

- 1) *Retrieving necessary spatial and non-spatial data of interest from the EA database.*
- 2) *Converting the EA data format to the IDRISI data format:* Detailed procedures are presented in Section 5.5.2, Data Format Conversion.
- 3) *Precisely matching image data with the data from the EA system, and merging them into one platform:* This can be achieved by following the procedures presented in PROCEDURE-7.2 in Section 7.3.6 (Multi-temporal Image Matching) and PROCEDURE-7.3 in Section 7.3.7 (Merging Remotely sensed data with Data from Other Data Sources).

Non-synthetic Classified Image Maps

The non-synthetic classified image maps are the maps created from classified remote sensing data. The difference between the creation of this type of image maps and the creation of the non-synthetic continuous-tone image maps is that a standard image classification operation needs to be carried out with the preprocessed remote sensing data. In addition, the creation of non-synthetic classified image maps does not need a radiometric enhancement operation. Thus, the basic procedures involved are as follows (figure 8.2 (a)):

[PROCEDURE-8.3]:

- 1) *Projection conversion, if the projection of the remote sensing image is different from the one used in national mapping*

- 2) *Spatial resolution conversion, if the resolution of the remotely sensed data is not compatible with national mapping scales*
- 3) *Carrying out image classification processing (refer to Chapter 6).*

Synthetic Classified Image Mapping

The methodology for the creation of the synthetic classified image maps is:

[PROCEDURE-8.4]:

- 1) *Applying the procedures of projection conversion, spatial resolution standardization and image classification processing used for the non-synthetic classified image mapping to preprocess a remote sensing image to create a non-synthetic classified image map.*
- 2) *Retrieving necessary spatial and non-spatial data of interest from the EA database, converting the EA data format to the IDRISI data format, and matching image data with the data from the EA system to create a required synthetic classified image map.*

The combination is shown in figure 8.2(b).

8.1.2 3-Dimensional Remote Sensing Image Mapping

Three-dimensional image mapping provides national mapping applications with a new mapping approach. It creates a realistic perspective view of the landscape for applications, such as natural resource management, planning, and environmental impact analysis. With the changes of view angle and view direction found in this type of maps, users can more easily read and analyze 3-dimensional distributions of land covers.

Figure 8.2 Procedures for The Creation of Non-Synthetic (a) and Synthetic (b)

Classified Image Maps on IDRISI

Four different types of 3-dimensional image maps, which correspond to 2-dimensional image mapping presented above, can be created using remote sensing data, namely, the non-synthetic and synthetic continuous-tone 3-D image maps, and, non-synthetic and synthetic classified 3-D image maps. The national coverage 3-D image maps must be created on the basis of the 2-D image maps previously generated and on the national coverage raster DEM data.

In addition to conducting the operations required for the generation of the four types of 2-D image maps described in the preceding section, the following procedures need to be followed, in order to create the four types of 3-D image maps on IDRISI:

[PROCEDURE-8.5]:

- 1) *Precisely matching raster DEM data with 2-D image maps of interest:* This is the essential requirement in the creation of 3-D image maps, which ensures that two data sets are spatially matched (refer to PROCEDURE-7.2 in Section 7.3.6, Multi-temporal Image Matching, and PROCEDURE-7.3 in Section 7.3.7, Merging Remotely sensed data with Data from Other Data Sources, for details).
- 2) *Creating a 3-D DEM image:* This can be achieved by using the IDRISI orthographical image mapping function <ORTHO> in the image display module.
- 3) *Draping the 2-D image map created previously onto the 3-D DEM image:* the IDRISI image draping function <ORTHO> can be used for this purpose.

The complete procedures are shown in figure 8.3.

8.1.3 Topographic Image Mapping

Topographic information is traditionally represented in two ways: contours or hill shading. A contour map can be thought of as a quantitative representation of topographic information in comparison with a shaded map. However, it is not as easy to read a contour map as it is to read a shaded map, since the hill shading approach provides a realistic representation of the earth's surface. This kind of hill shading map is especially useful for such applications

Figure 8.3 Procedures for The Creation of 3-Dimensional Image Maps on IDRISI

as natural resource management and land use planning. The traditional approach to the generation of hill shading maps is to manually add shade to contour maps. Several difficulties exist in this approach. Firstly, it is difficult to maintain a consistent map production standard over a whole map or over serial maps. Secondly, the production of this type of maps is highly dependent on the skill of cartographers. Finally, it is labour-intensive and the production efficiency is low. Image processing technology provides the generation of topographic shading maps with powerful tools. In a digital environment, consistent map quality control can be easily achieved, and production efficiency can be significantly improved.

2-Dimensional Topographic Image Mapping

In the current integration environment, a 2-dimensional topographic map can be created by using the following procedures:

[PROCEDURE-8.6]:

- 1) *Preparing DEM data of interest areas:* The data set can come directly from raster format digital elevation data, if available, or from contour maps of areas of interest. If contour maps are used for creating DEM data, they have to be digitized and converted into raster format.
- 2) *Conducting a projection conversion of DEM data:* Detail refers to PROCEDURE-6.1 presented in Section 6.3.2, Image Quality Control.
- 3) *Creating an illumination data file of the earth's surface from DEM data of interest.* This can be achieved by using the IDRISI hill shading creation function <SURFACE> organized in the GIS ring module of the system. In the creation of a topographic shading image map using the function <SURFACE>, users can easily choose viewing direction and viewing angle.
- 4) *Reranking the illumination data according to map shading requirements:* Users can reclassify the illumination data in order to produce a shading map which is specifically designed to the users' requirements. The IDRISI reclassification function <RECLASS> in the analytical module can be used for this purpose.
- 5) *Creating a 2-D topographic shading map:* This can be accomplished by using the IDRISI displaying function <COLOR> in the image displaying module.

3-Dimensional Topographic Image Maps

The generation of 3-D topographic image maps can be achieved on the basis of the 2-D topographic image maps created previously. In addition to using the procedures for 2-D map creation, the following procedures need to be carried out:

[PROCEDURE-8.7]:

- 1) *Creating a 3-D DEM image map:* This can be done by using the IDRISI orthographical image generation function <ORTHO> in the image display module.
- 2) *Draping the 2-D topographic image map created for the same area onto the 3-D DEM image:* the IDRISI image draping function provided by <ORTHO> can be used for this purpose.

The procedures involved in the creation of 2-D and 3-D topographic image maps are shown in figure 8.4 (a) and (b).

Figure 8.4 Procedures for the Creation of 2-D (a) and 3-D (b)

Topographic Image Maps on IDRISI

8.1.4 Statistical Image Mapping

A 3-dimensional statistical map or prism map is a very good visual representation of statistical areal data. On such a map, users can easily represent two or three different areal statistical variables of interest on the same area base, with one variable being represented as the height of the prism, and one or two others as a color map draped on the top of the prism. Thereby, users can easily discern the correlation and differences between variables.

However, traditional choropleth prism maps have a major drawback, namely, some of the map elements are hidden by others because of the inflexibility, in map production, in the selection of map viewing direction and angle. Also, the creation of this type of map faces the same problems as topographic shading maps.

Image processing technology, however, provides 3-dimensional statistical mapping with efficient tools. In a digital environment, users can easily change the viewing direction and viewing angle so as to create a prism map which can properly represent areal statistical data. Two types of data files are involved in the generation of this type of image maps. One, called a prism data file, is used for the generation of 3-D prism base maps. The other, called an overlaying data file, is used for the generation of the image maps to be draped onto the 3-D prism base map. The following are the basic procedures involved in the creation of a prism map in the current integration environment (figure 8.5):

[PROCEDURE-8.8]:

- 1) *Retrieving statistical areal data and boundary area data of interest from the EA database*

- 2) *Conducting format conversion:* The boundary area data from the EA database must be converted into the IDRISI data format in order to generate prism maps in the IDRISI environment. This can be achieved by using the IDRISI ARC/INFO-to-IDRISI format conversion function <ARCIDRIS> in the peripheral module.
- 3) *Converting the boundary data from vector format to raster format:* This can be done by using the IDRISI vector to raster conversion function <POLYRAS> in the data entry module.
- 4) *Creating a prism data file and an overlay data file:* This can be accomplished by assigning the statistical data to the related polygons. In the IDRISI environment, this is carried out by using the IDRISI reclassification function <RECLASS> in the analytical module.
- 5) *Reclassifying the overlay data file:* Since the IDRISI system can only display image data with 16 colors, all the related image data must be reclassified into a maximum of 16 levels before being used for image mapping. This operation can be carried out by using the IDRISI reclassification function <RECLASS>.
- 6) *Creating a 3-D prism image base map and a 2-D statistical image map to be draped onto the 3-D base map:* These can be carried out by using the IDRISI orthographical mapping function <ORTHO> and the image display function <COLOR> in the image displaying module.
- 7) *Draping the 2-D statistical image map onto the 3-D prism image:* The operation can be achieved by using the IDRISI image draping mechanism provided by the function <ORTHO>.

Fig. 8.5 Procedures for the Creation of 3-D Statistical Image Maps

8.2 TEMPORAL IMAGE MAPPING

8.2.1 Snapshot Temporal Image Mapping

Snapshot is one of the approaches most widely used in the representation of serial time data. The basic principle of this approach is that, first, serial time data are represented in slice data files, then the data are displayed on the screen slice by slice. By regulating the time interval in displaying two slices, users can create temporal image maps which create different perception effects. The changes in geographic phenomena can thereby be dynamically traced.

In the integration environment, eight different types of snapshot image maps can be created, namely, 2-dimensional and 3-dimensional, the non-synthetic and synthetic continuous-tone snapshot image maps, and the non-synthetic and synthetic classified snapshot image maps. Each slice of these temporal image maps can be created based on the methods discussed in Section 8.1.1 (2-D Remote Sensing Image Mapping) and Section 8.1.2 (3-D Remote Sensing Image Mapping). In addition to using the procedures for the atemporal image maps, the following procedures need to be carried out (see figure 8.6):

[PROCEDURE-8.9]:

1) *Image quality control (needed only for the continuous-tone snapshot image mapping):*

The details on the image quality control processing were discussed in PROCEDURE-6.1 presented in Section 6.3.2 (Image Quality Control).

Figure 8.6 Procedures for the Creation of Snapshot Image Maps on IDRISI

- 2) *Time serial image matching*: In order to correctly represent change on temporal image maps, it is necessary to precisely match all temporal images involved in a presentation (see PROCEDURE-7.2 presented in Section 7.3.6 (Multi-temporal Image Matching) for details).
- 3) *Creating a temporal image map file*: A temporal image data file needs to be created in the IDRISI environment in order to generate snapshot image maps. This file should include both a sequence of names of all the temporal image data involved, and time flags which indicate the time interval in the display of two slices.
- 4) *Generating snapshot image maps*: This can be achieved by using IDRISI image display function <COLOR T> in the image display module.

8.2.2 Asynchronic Temporal Image Mapping

The asynchronic image mapping approach, proposed in the integration, is an attempt to asynchronously display all the serial time data of interest on one screen. The basic principle of this approach is: first display the whole the time-1 image on screen, as shown in figure 8.7 (a), then start displaying time-2 image which cover time-1 image line by line. After time-2 image is displayed up to N lines (selection of number N is dependent on computer display speed), time-3 image starts to be displayed on screen covering the time-2 image, as shown in figure 8.7 (b) and (c). The remaining images are displayed in the same manner as time-2 and time-3 images, as presented in figure 8.7 (d). At this time, the displaying of time-2 to time-n images shares the same CPU time, but the program must automatically switch the displaying of each image one by one. Since all related temporal images are asynchronously displayed on the same screen, the dynamic changes of spatial information can easily be traced.

Figure 8.7 The Principle of The Asynchronous Image Mapping Approach

The basic procedures for the creation of asynchronous image maps, as shown in figure 8.8, are similar to those for snapshot image mapping. A few differences exist in the procedures of creating temporal image file and generating the temporal image used for snapshot image mapping in the preceding section. For asynchronous image mapping, the procedure of creating temporal image file is replaced by the creation of an asynchronous data file, in which the number of lines N and a list of names of time serial data files are included; and the procedure generating temporal image is replaced by the generation of asynchronous image maps.

8.2.3 Overlay Temporal Image Mapping

The overlay temporal mapping approach uses different colors or patterns to represent different serial time data on a single image map. The basic principle of the approach is that first an up-to-date image is displayed as an area-filled image on the screen. Then, the remaining temporal data, which should be organized in vector format, are overlaid onto the area-filled image with different colors or patterns for each time slice data. Care needs to be taken in using this approach, since several time points of spatial phenomena are to be represented on a single image map, and information overloading may happen.

In the current integration environment, the creation of overlay temporal image maps can be achieved by using the following procedures (figure 8.9):

Fig. 8.8 Procedures for The Creation of Asynchronous Image Maps

[PROCEDURE-8.10]:

- 1) *Time serial image matching*: As in snapshot image mapping, precise matching of all temporal image data involved is required for overlay image mapping. Detail refers to the PROCEDURE-7.2 presented in Section 7.3.6 (Multi-temporal Image Matching) for details).
- 2) *Vectorization of time 1 to time N-1 image data*: This is necessary if the vector and raster overlaid approach is used in the creation of overlay temporal image maps. This can be achieved through the use of the IDRISI raster-to-vector conversion function <POLYVEC> in the data manipulations module.
- 3) *Generating overlay temporal image maps*: There are two approaches for creating overlaid temporal image maps. One is achieved by using the vector and raster overlay operation. The other is achieved by using the raster overlay operation. If the first approach is adopted, the IDRISI vector and raster data overlay function, provided by the function <COLOR> can be used. When using this function, the time-N image will be displayed on the screen first, then users will be requested to enter "V" in order to activate the overlay function, to input the name of the vector data file, and to give a color code, which assigns a color to the vector data layer. Theoretically, there is no limitation to the number of vector overlays.

If all images are intended to be overlaid in raster format, then the IDRISI raster overlay function <OVERLAY> in the analytical module can be used. However, if the raster overlay approach is used, users need to ensure that only one of all the related temporal images (in most cases, an up-to-date image) be represented in area-filled format, whereas the rest be represented in outline-based format, i.e., only boundaries of land coverages are presented on the image maps. Otherwise, after overlaying, all temporal information will be mixed, and recognizing specific serial temporal data will be extremely difficult.

Figure 8.9 Procedures for the Creation of Overlaid Temporal Image Maps on IDRISI

CHAPTER 9

EXPERIMENTS

This chapter presents the experiments conducted in the integration project, as well as brief analyses of the results. The experiments carried out are mainly an attempt to test the functionality needed in the integration of the EA and IDRISI systems. The experiments addressed include image classification, image post-processing and image mapping, which correspond to the principles and procedures discussed in Chapter 6 (Thematic Information Extraction for National Mapping), Chapter 7 (Image Post-Processing) and Chapter 8 (Image Mapping).

9.1 IMAGE CLASSIFICATION

The following image classification experiments, through the use of the maximum likelihood approach, the minimum distance approach and the parallelepiped approach, are conducted on the basis of the same data set, namely, the NOAA AVHRR band 1 and band 4 of the Prairie Provinces of Canada, and the normalized difference vegetation index (NDVI) data derived from the NOAA AVHRR band 1 and band 2 data of the same areas. The resolution of the data set is 4 km x 4 km.

The classification procedures based on the three approaches were presented in Section 6.6.1 (Supervised Classification Methodologies).

9.1.1 Image Classification Based on the Maximum Likelihood Approach

The classified result derived from the maximum likelihood approach is shown in image 2, in which the green represents vegetation coverage areas; the pink represents agricultural

[illegible]

IMAGE 2

1. Introduction
 2. Background
 3. Methodology
 4. Results
 5. Conclusion
 6. References

croplands, the blue represents snow and water bodies, and the white represents unclassified pixels resulting from the use of thresholding in image classification. It took about 15 minutes to classify this image in IDRISI. When visually compared with the classified AVHRR image of the Prairie Provinces conducted by the Manitoba Remote Sensing Center, the classified image processed through the use of the maximum likelihood approach is of the highest accuracy among the classified results created from the three classifiers.

9.1.2 Image Classification Based on the Minimum Distance Approach

Image 3 shows the classified result of AVHRR images of the Prairie Provinces through the use of the minimum distance approach. It took about 9 minutes to process the image in IDRISI. The land covers are: vegetation coverage in green, snow and water bodies in blue, agricultural croplands in light red, and unclassified pixels (because of the use of thresholding) in yellow. The result shown in image 3 is very similar to that presented in image 2, but in image 3, it can be seen that there is more agricultural cropland, on the right half than on image 2. Most of these areas should be vegetation coverage areas and are incorrectly classified. There are also more unclassified areas. There are more incorrectly classified pixels in Image 3. This was caused by the drawback of the Minimum Distance approach and the spectral characteristics of the used remote sensing image. One reason is, as shown in Table 3 and figure 6.3, that the spectral distributions of three land covers are seriously overlaid; the spectrally-inseparable problem partially resulted in the image misclassification. The other reason is, as indicated in Section 6.6.2 (Operational Comparison of Supervised Image Classification Approaches), elongated classes could not be well modelled, because of the ignorance of the covariance data in the classification.

IMAGE 3

9.1.3 Image Classification Based on the Parallelepiped Approach

Image 4 presents the classified result of AVHRR images of the Prairie Provinces processed on the basis of the parallelepiped classification approach. About 2 minutes is needed to generate this image in 'DRISI. Because of the overlay of spectral reflectance of the three land categories, the classified result shows the lowest classification accuracy, which can be easily recognized when comparing image 4 with classified remote sensing images provided by the Manitoba Remote Sensing Center. Similar to the reasons for the image misclassification based on the Minimum Distance approach, the image misclassification in Image 4 is resulted from the inherent drawback of the Parallelepiped approach and the overlaid problem of the spectral distributions of three land covers in the used remote sensing image. As discussed in Section 6.6.2 (Operational Comparison of Supervised Image Classification Approaches), the MLH approach will produce the highest accuracy classification result of the three classification approaches if adequate training areas are available, while the classification results based on the parallelepiped approach are of the lowest accuracy unless each of land categories has a very distinct spectral characteristics. The above classification results coincide with the analysis. Therefore, in most cases, it is recommended that users utilize the MLH and the minimum distance approaches in conducting image classification.

9.2 IMAGE POST-PROCESSING

The experiments in image post-processing include raster image-to-vector image conversion, classification "noise" handling, and data format conversion "noise" handling.

IMAGE 4

1 1 1 1 1 1 1 1 1 1

9.2.1 Raster-to-Vector Conversion

The raster-to-vector format conversion is an important operation in image post-processing, since data exchange between the EA and the IDRISI systems is based on a vector format, while the classified remote sensing images are in raster format. A window data set (the Winnipeg Lake area) of the classified image map of Prairie Provinces, which has been processed through the use of the maximum likelihood approach, is used to test the raster-to-vector conversion operation. The window image is shown in image 5.

Image 6 (a) presents the format conversion result of image 5. The data processing procedures involved follow PROCEDURE-7.1 presented in Section 7.3.1 (Format Conversion). The experiment shows that the processing of data format conversion is the longest of all operations involved in the experiments (about 6 hours for an image of three land covers with size: 160 x 150 pixels). Both the classification "noise" polygons and format conversion "noise" (i.e., saw-shape boundary) can be clearly seen in image 6 (a). Because the EA system is incapable of handling island map objects, the thematic data in vector format, which are directly vectorized from classified remote sensing images, cannot be sent to the EA system. Thus, a layered vectorization strategy is used in raster-to-vector conversion of classified remote sensing data, in order to ensure that there are no island polygons in each thematic layer of vector format remote sensing image (see Section 7.3.1 (Format Conversion)). The results are shown in image 6 (b), (c) and (d), which correspond to the water layer, the cropland layer and the vegetation layer.

9.2.2 Classification "Noise" Handling

The data set used for the experiment of classification "noise" handling is shown in image 6(b). In this experiment, the image objects with 10 pixels are considered "noise", and the

Figure 1. Aerial photograph of the study area, showing the location of the study area.

Figure 2. Aerial photograph of the study area, showing the location of the study area.

Figure 3. Aerial photograph of the study area, showing the location of the study area.

Vector Format Window Image of The Peace Province with Data

IMAGE 6(A)

10.10.10.1

Small black and white photograph showing a close-up of a textured surface, possibly a rock or mineral specimen, with a small black square marker visible in the lower right corner.

IMAGE 6(B)

Small black and white photograph showing a close-up of a textured surface, possibly a rock or mineral specimen, with a small black square marker visible in the lower right corner.

The figure consists of 18 small diagrams arranged vertically, each showing a set of points (circles) and lines (solid and dashed). The points are labeled with numbers 1 through 18. The lines are labeled with letters A through Z. The diagrams illustrate the steps of the algorithm, showing how the points and lines evolve as the algorithm progresses. The points are initially arranged in a grid, and the lines are drawn between them. As the algorithm progresses, the points move and the lines change, eventually forming a complex structure.

IMAGE 6(C)

to provide
Page 60 -
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-

Vector Format Data of Image 5 (Vegetation Layer)

IMAGE 6(D)

Figure 15

processing methods used are the ones presented in Section 7.3.2 ("Noise" Filtering). When using the function <EXNOISE> to filter noise, users can select different "noise" thresholds, e.g., two, three or more pixels, according to specific mapping requirements. The processed result is presented in image 7.

9.2.3 Format Conversion "Noise" Handling

As discussed in Section 7.3.2 ("Noise" Handling), data format conversion "noise" must be filtered when applying classified remotely sensed data to national mapping. The data set used for this experiment is the data shown in image 7, and the operation is carried out through the use of the IDRISI line generalization function <LINEGEN>. The processing procedures followed were presented in Section 7.3.2 ("Noise" Handling). In order to illustrate the functionality and problems of format conversion "noise" handling in the IDRISI environment, the data shown in image 6 (b) and image 8, a vector DEM map converted from raster DEM data, are used. The processed results of image 6 (b) and image 8 data based on the IDRISI function <LINEGEN> are shown in images 9 (a) and (b), images 10 (a) and (b), and, images 11 (a) and (b), which are corresponding to three different generalization approaches. Namely, images 9 (a) and (b) are the results of the Douglas-Peucker approach (with tolerance 0.7 pixel); images 10 (a) and (b) are the results of the low pass filtering approach (with threshold 3 pixels); and images 11 (a) and (b) are the results of the point selection approach (with 3 pixels threshold). It can be recognized that there are some sliver polygons present in the processed results shown in images 9 (a), 10 (a) and 11 (a). This effect results from a drawback of the IDRISI vector data structure. In the IDRISI vector format, any boundary line which is shared by two polygons (namely, two landcover types) is stored twice in the vector chains of the two polygons which share this common segment. In consequence, when a generalization operation is carried out, all the common segments are generalized twice beginning with different start and end points of

Figure 7. Result of the thresholding operation (Threshold = 10 pixels)

Image 7

DEM Data Set File Format Conversion "Nile" Handline

IMAGE 8

1000000

Figure 9(A) shows the results of the analysis of the data from the first two experiments.

Figure 9(A)

1000

IMAGE 9(A)

IMAGE 9(B)

20 21 1-1-1-1

[illegible]

10
 11
 12
 13
 14
 15

IMAGE 10(A)

Figure 10(B) shows the distribution of the

IMAGE 10(B)

10100001

Figure 11(a) shows the building layout (Point-to-Point)

Figure 11(a)

Figure 11(b)

Figure 11(B) shows the handling process of the

Figure 11(B)

IMAGE 11(B)

polygons chains, and hence, the sliver polygons are created.

Therefore, in order to deal with the side-effect caused by the drawback of the IDRISI vector format, it is recommended that the layered vectorization strategy be used in the raster-to-vector format conversion of classified remote sensing data, if format conversion "noise" is to be handled in the IDRISI environment. Otherwise, it is recommended that this type of "noise" handling be carried out through the use of the ARC/INFO line generalization function.

Except for the above drawback, performance comparisons of these three algorithms indicated that the low-pass algorithm produces the best format conversion "noise" handling result that most precisely fits its original data among the three algorithms. This result can be easily identified by overlaying the handling results based on three different algorithms on the original data set.

9.3 IMAGE MAPPING

The experiments in image mapping include: 2-D non-synthetic and synthetic continuous-tone image mapping, 2-D non-synthetic and synthetic classified image mapping, 3-D non-synthetic and synthetic continuous-tone image mapping, 2-D and 3-D topographic image mapping, 3-D statistical image mapping, snapshot temporal image mapping, and overlaid temporal image mapping. These image mapping functions will provide the national mapping program with diverse mapping approaches.

9.3.1 2-D Non-Synthetic Continuous-Tone Image Mapping

The remotely sensed data used for 2-D non-synthetic continuous-tone image mapping are the NOAA AVHRR band 4 data of the Prairie Provinces with 4 km x 4 km spatial

Figure 10-11 12-13 14-15 16-17 18-19 20-21 22-23 24-25 26-27 28-29 30-31 32-33 34-35 36-37 38-39 40-41 42-43 44-45 46-47 48-49 50-51 52-53 54-55 56-57 58-59 60-61 62-63 64-65 66-67 68-69 70-71 72-73 74-75 76-77 78-79 80-81 82-83 84-85 86-87 88-89 90-91 92-93 94-95 96-97 98-99 100-101 102-103 104-105 106-107 108-109 110-111 112-113 114-115 116-117 118-119 120-121 122-123 124-125 126-127 128-129 130-131 132-133 134-135 136-137 138-139 140-141 142-143 144-145 146-147 148-149 150-151 152-153 154-155 156-157 158-159 160-161 162-163 164-165 166-167 168-169 170-171 172-173 174-175 176-177 178-179 180-181 182-183 184-185 186-187 188-189 190-191 192-193 194-195 196-197 198-199 200-201 202-203 204-205 206-207 208-209 210-211 212-213 214-215 216-217 218-219 220-221 222-223 224-225 226-227 228-229 230-231 232-233 234-235 236-237 238-239 240-241 242-243 244-245 246-247 248-249 250-251 252-253 254-255 256-257 258-259 260-261 262-263 264-265 266-267 268-269 270-271 272-273 274-275 276-277 278-279 280-281 282-283 284-285 286-287 288-289 290-291 292-293 294-295 296-297 298-299 300-301 302-303 304-305 306-307 308-309 310-311 312-313 314-315 316-317 318-319 320-321 322-323 324-325 326-327 328-329 330-331 332-333 334-335 336-337 338-339 340-341 342-343 344-345 346-347 348-349 350-351 352-353 354-355 356-357 358-359 360-361 362-363 364-365 366-367 368-369 370-371 372-373 374-375 376-377 378-379 380-381 382-383 384-385 386-387 388-389 390-391 392-393 394-395 396-397 398-399 400-401 402-403 404-405 406-407 408-409 410-411 412-413 414-415 416-417 418-419 420-421 422-423 424-425 426-427 428-429 430-431 432-433 434-435 436-437 438-439 440-441 442-443 444-445 446-447 448-449 450-451 452-453 454-455 456-457 458-459 460-461 462-463 464-465 466-467 468-469 470-471 472-473 474-475 476-477 478-479 480-481 482-483 484-485 486-487 488-489 490-491 492-493 494-495 496-497 498-499 500-501 502-503 504-505 506-507 508-509 510-511 512-513 514-515 516-517 518-519 520-521 522-523 524-525 526-527 528-529 530-531 532-533 534-535 536-537 538-539 540-541 542-543 544-545 546-547 548-549 550-551 552-553 554-555 556-557 558-559 560-561 562-563 564-565 566-567 568-569 570-571 572-573 574-575 576-577 578-579 580-581 582-583 584-585 586-587 588-589 590-591 592-593 594-595 596-597 598-599 600-601 602-603 604-605 606-607 608-609 610-611 612-613 614-615 616-617 618-619 620-621 622-623 624-625 626-627 628-629 630-631 632-633 634-635 636-637 638-639 640-641 642-643 644-645 646-647 648-649 650-651 652-653 654-655 656-657 658-659 660-661 662-663 664-665 666-667 668-669 670-671 672-673 674-675 676-677 678-679 680-681 682-683 684-685 686-687 688-689 690-691 692-693 694-695 696-697 698-699 700-701 702-703 704-705 706-707 708-709 710-711 712-713 714-715 716-717 718-719 720-721 722-723 724-725 726-727 728-729 730-731 732-733 734-735 736-737 738-739 740-741 742-743 744-745 746-747 748-749 750-751 752-753 754-755 756-757 758-759 760-761 762-763 764-765 766-767 768-769 770-771 772-773 774-775 776-777 778-779 780-781 782-783 784-785 786-787 788-789 790-791 792-793 794-795 796-797 798-799 800-801 802-803 804-805 806-807 808-809 810-811 812-813 814-815 816-817 818-819 820-821 822-823 824-825 826-827 828-829 830-831 832-833 834-835 836-837 838-839 840-841 842-843 844-845 846-847 848-849 850-851 852-853 854-855 856-857 858-859 860-861 862-863 864-865 866-867 868-869 870-871 872-873 874-875 876-877 878-879 880-881 882-883 884-885 886-887 888-889 890-891 892-893 894-895 896-897 898-899 900-901 902-903 904-905 906-907 908-909 910-911 912-913 914-915 916-917 918-919 920-921 922-923 924-925 926-927 928-929 930-931 932-933 934-935 936-937 938-939 940-941 942-943 944-945 946-947 948-949 950-951 952-953 954-955 956-957 958-959 960-961 962-963 964-965 966-967 968-969 970-971 972-973 974-975 976-977 978-979 980-981 982-983 984-985 986-987 988-989 990-991 992-993 994-995 996-997 998-999 1000-1001 1002-1003 1004-1005 1006-1007 1008-1009 1010-1011 1012-1013 1014-1015 1016-1017 1018-1019 1020-1021 1022-1023 1024-1025 1026-1027 1028-1029 1030-1031 1032-1033 1034-1035 1036-1037 1038-1039 1040-1041 1042-1043 1044-1045 1046-1047 1048-1049 1050-1051 1052-1053 1054-1055 1056-1057 1058-1059 1060-1061 1062-1063 1064-1065 1066-1067 1068-1069 1070-1071 1072-1073 1074-1075 1076-1077 1078-1079 1080-1081 1082-1083 1084-1085 1086-1087 1088-1089 1090-1091 1092-1093 1094-1095 1096-1097 1098-1099 1100-1101 1102-1103 1104-1105 1106-1107 1108-1109 1110-1111 1112-1113 1114-1115 1116-1117 1118-1119 1120-1121 1122-1123 1124-1125 1126-1127 1128-1129 1130-1131 1132-1133 1134-1135 1136-1137 1138-1139 1140-1141 1142-1143 1144-1145 1146-1147 1148-1149 1150-1151 1152-1153 1154-1155 1156-1157 1158-1159 1160-1161 1162-1163 1164-1165 1166-1167 1168-1169 1170-1171 1172-1173 1174-1175 1176-1177 1178-1179 1180-1181 1182-1183 1184-1185 1186-1187 1188-1189 1190-1191 1192-1193 1194-1195 1196-1197 1198-1199 1200-1201 1202-1203 1204-1205 1206-1207 1208-1209 1210-1211 1212-1213 1214-1215 1216-1217 1218-1219 1220-1221 1222-1223 1224-1225 1226-1227 1228-1229 1230-1231 1232-1233 1234-1235 1236-1237 1238-1239 1240-1241 1242-1243 1244-1245 1246-1247 1248-1249 1250-1251 1252-1253 1254-1255 1256-1257 1258-1259 1260-1261 1262-1263 1264-1265 1266-1267 1268-1269 1270-1271 1272-1273 1274-1275 1276-1277 1278-1279 1280-1281 1282-1283 1284-1285 1286-1287 1288-1289 1290-1291 1292-1293 1294-1295 1296-1297 1298-1299 1300-1301 1302-1303 1304-1305 1306-1307 1308-1309 1310-1311 1312-1313 1314-1315 1316-1317 1318-1319 1320-1321 1322-1323 1324-1325 1326-1327 1328-1329 1330-1331 1332-1333 1334-1335 1336-1337 1338-1339 1340-1341 1342-1343 1344-1345 1346-1347 1348-1349 1350-1351 1352-1353 1354-1355 1356-1357 1358-1359 1360-1361 1362-1363 1364-1365 1366-1367 1368-1369 1370-1371 1372-1373 1374-1375 1376-1377 1378-1379 1380-1381 1382-1383 1384-1385 1386-1387 1388-1389 1390-1391 1392-1393 1394-1395 1396-1397 1398-1399 1400-1401 1402-1403 1404-1405 1406-1407 1408-1409 1410-1411 1412-1413 1414-1415 1416-1417 1418-1419 1420-1421 1422-1423 1424-1425 1426-1427 1428-1429 1430-1431 1432-1433 1434-1435 1436-1437 1438-1439 1440-1441 1442-1443 1444-1445 1446-1447 1448-1449 1450-1451 1452-1453 1454-1455 1456-1457 1458-1459 1460-1461 1462-1463 1464-1465 1466-1467 1468-1469 1470-1471 1472-1473 1474-1475 1476-1477 1478-1479 1480-1481 1482-1483 1484-1485 1486-1487 1488-1489 1490-1491 1492-1493 1494-1495 1496-1497 1498-1499 1500-1501 1502-1503 1504-1505 1506-1507 1508-1509 1510-1511 1512-1513 1514-1515 1516-1517 1518-1519 1520-1521 1522-1523 1524-1525 1526-1527 1528-1529 1530-1531 1532-1533 1534-1535 1536-1537 1538-1539 1540-1541 1542-1543 1544-1545 1546-1547 1548-1549 1550-1551 1552-1553 1554-1555 1556-1557 1558-1559 1560-1561 1562-1563 1564-1565 1566-1567 1568-1569 1570-1571 1572-1573 1574-1575 1576-1577 1578-1579 1580-1581 1582-1583 1584-1585 1586-1587 1588-1589 1590-1591 1592-1593 1594-1595 1596-1597 1598-1599 1600-1601 1602-1603 1604-1605 1606-1607 1608-1609 1610-1611 1612-1613 1614-1615 1616-1617 1618-1619 1620-1621 1622-1623 1624-1625 1626-1627 1628-1629 1630-1631 1632-1633 1634-1635 1636-1637 1638-1639 1640-1641 1642-1643 1644-1645 1646-1647 1648-1649 1650-1651 1652-1653 1654-1655 1656-1657 1658-1659 1660-1661 1662-1663 1664-1665 1666-1667 1668-1669 1670-1671 1672-1673 1674-1675 1676-1677 1678-1679 1680-1681 1682-1683 1684-1685 1686-1687 1688-1689 1690-1691 1692-1693 1694-1695 1696-1697 1698-1699 1700-1701 1702-1703 1704-1705 1706-1707 1708-1709 1710-1711 1712-1713 1714-1715 1716-1717 1718-1719 1720-1721 1722-1723 1724-1725 1726-1727 1728-1729 1730-1731 1732-1733 1734-1735 1736-1737 1738-1739 1740-1741 1742-1743 1744-1745 1746-1747 1748-1749 1750-1751 1752-1753 1754-1755 1756-1757 1758-1759 1760-1761 1762-1763 1764-1765 1766-1767 1768-1769 1770-1771 1772-1773 1774-1775 1776-1777 1778-1779 1780-1781 1782-1783 1784-1785 1786-1787 1788-1789 1790-1791 1792-1793 1794-1795 1796-1797 1798-1799 1800-1801 1802-1803 1804-1805 1806-1807 1808-1809 1810-1811 1812-1813 1814-1815 1816-1817 1818-1819 1820-1821 1822-1823 1824-1825 1826-1827 1828-1829 1830-1831 1832-1833 1834-1835 1836-1837 1838-1839 1840-1841 1842-1843 1844-1845 1846-1847 1848-1849 1850-1851 1852-1853 1854-1855 1856-1857 1858-1859 1860-1861 1862-1863 1864-1865 1866-1867 1868-1869 1870-1871 1872-1873 1874-1875 1876-1877 1878-1879 1880-1881 1882-1883 1884-1885 1886-1887 1888-1889 1890-1891 1892-1893 1894-1895 1896-1897 1898-1899 1900-1901 1902-1903 1904-1905 1906-1907 1908-1909 1910-1911 1912-1913 1914-1915 1916-1917 1918-1919 1920-1921 1922-1923 1924-1925 1926-1927 1928-1929 1930-1931 1932-1933 1934-1935 1936-1937 1938-1939 1940-1941 1942-1943 1944-1945 1946-1947 1948-1949 1950-1951 1952-1953 1954-1955 1956-1957 1958-1959 1960-1961 1962-1963 1964-1965 1966-1967 1968-1969 1970-1971 1972-1973 1974-1975 1976-1977 1978-1979 1980-1981 1982-1983 1984-1985 1986-1987 1988-1989 1990-1991 1992-1993 1994-1995 1996-1997 1998-1999 2000-2001 2002-2003 2004-2005 2006-2007 2008-2009 2010-2011 2012-2013 2014-2015 2016-2017 2018-2019 2020-2021 2022-2023 2024-2025 2026-2027 2028-2029 2030-2031 2032-2033 2034-2035 2036-2037 2038-2039 2040-2041 2042-2043 2044-2045 2046-2047 2048-2049 2050-2051 2052-2053 2054-2055 2056-2057 2058-2059 2060-2061 2062-2063 2064-2065 2066-2067 2068-2069 2070-2071 2072-2073 2074-2075 2076-2077 2078-2079 2080-2081 2082-2083 2084-2085 2086-2087 2088-2089 2090-2091 2092-2093 2094-2095 2096-2097 2098-2099 2100-2101 2102-2103 2104-2105 2106-2107 2108-2109 2110-2111 2112-2113 2114-2115 2116-2117 2118-2119 2120-2121 2122-2123 2124-2125 2126-2127 2128-2129 2130-2131 2132-2133 2134-2135 2136-2137 2138-2139 2140-2141 2142-2143 2144-2145 2146-2147 2148-2149 2150-2151 2152-2153 2154-2155 2156-2157 2158-2159 2160-2161 2162-2163 2164-2165 2166-2167 2168-2169 2170-2171 2172-2173 2174-2175 2176-2177 2178-2179 2180-2181 2182-2183 2184-2185 2186-2187 2188-2189 2190-2191 2192-2193 2194-2195 2196-2197 2198-2199 2200-2201 2202-2203 2204-2205 2206-2207 2208-2209 2210-2211 2212-2213 2214-2215 2216-2217 2218-2219 2220-2221 2222-2223 2224-2225 2226-2227 2228-2229 2230-2231 2232-2233 2234-2235 2236-2237 2238-2239 2240-2241 2242-2243 2244-2245 2246-2247 2248-2249 2250-2251 2252-2253 2254-2255 2256-2257 2258-2259 2260-2261 2262-2263 2264-2265 2266-2267 2268-2269 2270-2271 2272-2273 2274-2275 2276-2277 2278-2279 2280-2281 2282-2283 2284-2285 2286-2287 2288-2289 2290-2291 2292-2293 2294-2295 2296-2297 2298-2299 2300-2301 2302-2303 2304-2305 2306-2307 2308-2309 2310-2311 2312-2313 2314-2315 2316-2317 2318-2319 2320-2321 2322-2323 2324-2325 2326-2327 2328-2329 2330-2331 2332-2333 2334-2335 2336-2337 2338-2339 2340-2341 2342-2343 2344-2345 2346-2347 2348-2349 2350-2351 2352-2353 2354-2355 2356-2357 2358-2359 2360-2361 2362-2363 2364-2365 2366-2367 2368-2369 2370-2371 2372-2373 2374-2375 2376-2377 2378-2379 2380-2381 2382-2383 2384-2385 2386-2387 2388-2389 2390-2391 2392-2393 2394-2395 2396-2397 2398-2399 2400-2401 2402-2403 2404-2405 2406-2407 2408-2409 2410-2411 2412-2413 2414-2415 2416-2417 2418-2419 2420-2421 2422-2423 2424-2425 2426-2427 2428-2429 2430-2431 2432-2433 2434-2435 2436-2437 2438-2439 2440-2441 2442-2443 2444-2445 2446-2447 2448-2449 2450-2451 2452-2453 2454-2455 2456-2457 2458-2459 2460-2461 2462-2463 2464-2465 2466-2467 2468-2469 2470-2471 2472-2473 2474-2475 2476-2477 2478-2479 2480-2481 2482-2483 2484-2485 2486-2487 2488-2489 2490-2491 2492-2493 2494-2495 2496-2497 2498-2499 2500-2501 2502-2503 2504-2505 2506-2507 2508-2509 2510-2511 2512-2513 2514-2515 2516-2517 2518-2519 2520-2521 2522-2523 2524-2525 2526-2527 2528-2529 2530-2531 2532-2533 2534-2535 2536-2537 2538-2539 2540-2541 2542-2543 2544-2545 2546-2547 2548-2549 2550-2551 2552-2553 2554-2555 2556-2557 2558-2559 2560-2561 2562-2563 2564-2565 2566-2567 2568-2569 2570-2571 2572-2573 2574-2575 2576-2577 2578-2579 2580-2581 2582-2583 2584-2585 2586-2587 2588-2589 2590-2591 2592-2593 2594-2595 2596-2597 2598-2599 2600-2601 2602-2603 2604-2605 2606-2607 2608-2609 2610-2611 2612-2613 2614-2615 2616-2617 2618-2619 2620-2621 2622-2623 2624-2625 2626-2627 2628-2629 2630-2631 2632-2633 2634-2635 2636-2637 2638-2639 2640-2641 2642-2643 2644-2645 2646-2647 2648-2649 2650-2651 2652-2653 2654-2655 2656-2657 2658-2659 2660-2661 2662-2663 2664-2665 2666-2667 2668-2669 2670-2671 2672-2673 2674-2675 2676-2677 2678-2679 2680-2681 2682-2683 2684-2685 2686-2687 2688-2689

resolution. The data processing procedure involved is PROCEDURE-8.1 presented in Section 8.1.1 (2-D Remote Sensing Image Mapping). The 2-D non-synthetic continuous-tone image mapping produced are presented in image 12.

9.3.2 2-D Synthetic Continuous-Tone Image Mapping

The remotely sensed data used in the creation of the 2-D synthetic continuous-tone image map are the same as those used in the creation of the 2-D synthetic continuous-tone image map. The thematic data overlaid are the census boundary data of the Prairie Provinces. The data processing procedure involved is PROCEDURE-8.2 presented in Section 8.1.1 (2-D Remote Sensing Image Mapping). The image produced is shown in image 13.

9.3.3 2-D Non-Synthetic Classified Image Mapping

The image data used for 2-D non-synthetic classified image mapping is the classified image of the Prairie Provinces of Canada (processed through the use of the maximum likelihood approach). The data processing procedure involved is PROCEDURE-8.3 presented in Section 8.1.1 (2-D Remote Sensing Image Mapping). The image map is shown in image 2.

9.3.4 2-D Synthetic Classified Image Mapping

Two-dimensional synthetic classified image mapping is one of the fundamental applications of remotely sensed data to the national mapping program. The remotely sensed data used are the classified image data of the Prairie Provinces of Canada as discussed in Section 9.1.1 (Image Classification Based on the Maximum Likelihood Approach). The thematic data overlaid on the classified remote sensing are the census boundary data of the Prairie Provinces. The data processing procedure involved is PROCEDURE-8.4, presented in

Figure 13: 2-D Synthetic Seismic Data (see text)

IMAGE 13

1000000

Section 8.1.1 (2-D Remote Sensing Image Mapping). The 2-dimensional synthetic classified image map created is presented in image 14.

9.3.5 3-D Non-Synthetic Continuous-Tone Image Mapping

The image data used in the experiment of 3-D non-synthetic continuous-tone image mapping are a national coverage NDVI image of Canada which was derived from NOAA AVHRR band 1 and band 4 data of the same area (no data available for the Arctic areas), and a national coverage DEM data for Canada, with the same spatial resolution and the same projection as those of remote sensing images. The data processing procedure involved is PROCEDURE-8.5 presented in Section 8.1.2 (3-D Remote Sensing Image Mapping), and the image map created is shown in image 15.

9.3.6 3-D Synthetic Continuous-Tone Image Mapping

The image data and the DEM data used for the creation of the 3-D synthetic continuous-tone image map are the same as those used in the experiment of 3-D non-synthetic continuous-tone image mapping. Additionally, the thematic data of the national political boundaries of Canada are overlaid on 3-D non-synthetic continuous-tone image map, in order to create a 3-D synthetic image map. The result is shown in image 16.

The data processing procedure involved is PROCEDURE-8.5 presented in Section 8.1.2 (3-D Remote Sensing Image Mapping).

9.3.7 2-D Topographic Image Mapping

As discussed in Section 8.1.3 (Topographic Image Mapping), 2-D and 3-D topographic image mapping can be considered by-products of the digital remote sensing image mapping technique. Users can efficiently create required 2-D and 3-D topographic image maps in

Figure 13 shows the typical results from the

7-11-15-1

IMAGE 14

IMAGE 15

IMAGE 16

the integrated environment. In the experiment, the DEM data involved is provided by the IDRISI system, and the data processing procedure involved is PROCEDURE-8.6 presented in Section 8.1.3 (Topographic Image Mapping). This experiment is conducted to test the topographic mapping capability of the IDRISI system for national mapping. The result is shown in image 17.

9.3.8 3-D Topographic Image Mapping

The DEM data used in 3-D topographic image mapping is the same data set as that used for 2-D topographic image mapping, and the data processing procedure involved is PROCEDURE-8.7 presented in Section 8.1.3 (Topographic Image Mapping). The 3-D topographic image map created is shown in image 18. Users can, according to their specific requirements, select different viewing angles and viewing directions, and different colors for shading maps in the creation of 3-D topographic image maps in the IDRISI environment.

This technique can be conveniently used to create 2-D and 3-D national coverage relief maps of Canada based on a national coverage DEM data set. Together with the raster data transfer technique to be implemented (see Section 9.4, Transfer of Remotely Sensed Data to EA), the 2-D and 3-D topographic maps created in IDRISI can efficiently transferred to and used in the EA environment for national electronic mapping applications.

9.3.9 3-D Statistical Image Mapping

Three-dimensional statistical image mapping can also be considered a by-product of the digital remote sensing image mapping technique of the integration. The most apparent advantages of this type of image mapping in the digital remote sensing image mapping environment are the high operation efficiency and the considerable flexibility in digital map

IMAGE 17

IMAGE 18

production. Users can easily change viewing angle and viewing direction in order to select a proper perspective in creating this type of image maps.

Two data sets, called a prism data file and an overlaying data file, are involved in the experiment of creating 3-D statistical image maps. The prism data is created from the statistical data of 1961 self-employment for each province of Canada; and the overlaying data file is created from the 1961 statistical data of experienced labour force in industry in Canada (data are from the Fourth Edition of the National Atlas of Canada). The result is shown in image 19. The data processing procedure followed is the PROCEDURE-8.8 presented in Section 8.1.4 (3-D Statistical Image Mapping).

9.3.10 Snapshot Temporal Image Mapping

The snapshot temporal image mapping approach is one of the most commonly used approaches in the representation of temporal information. It provides the national mapping program with a realistic temporal data representation. Users can easily trace dynamic change in spatial and non-spatial information with this type of image maps. A set of monthly NDVI image data of Africa (12 images) is used in the experiment. The basic procedure followed is PROCEDURE-8.9 presented in Section 8.2.1 (Snapshot Temporal Image Mapping).

Through changing the time interval in the display of two slices, users can create temporal image maps with different visual perception.

9.3.11 Overlay Temporal Image Mapping

The map elements in the experimental overlay temporal image map conducted are represented through the use of different colors (with 256 colors). The image shown in

IMAGE 19

image 20 is created based on PROCEDURE-8.10 presented in Section 8.2.3 (Overlay Temporal Image Mapping). The data involved is only a test data set created in the experiment.

The only pattern, which can be used to represent temporal information in the IDRISI environment, is the use of different colors.

9.4 DATA TRANSFER BETWEEN EA AND IDRISI

9.4.1 Transfer of Remotely Sensed Data from IDRISI to EA

In addition to the experiment conducted in Section 5.6 (Functionality Test), where a land use map (figure 5.7) in the IDRISI vector format was sent to and displayed in the EA environment, a classified vegetation distribution image (from a NOAA AVHRR image) of the Prairie Province was partially transferred to the EA system, i.e., the island polygon layer data. In the processing of this image, two basic factors were taken into account: the representation requirements of map elements in national mapping and the incapability of the EA system in handling island polygons at the present time. The first factor means that two basic image post-processing operations must be carried out on the spatial data (from remotely sensed images) to be used for national mapping, namely, classification "noise" handling and format conversion "noise" handling, while the second factor implies that the spatial data to be sent to the EA system has to be island-polygon-free data. Thus, in order to provide a vegetation distribution map of the Prairie Provinces that is satisfactory with the above requirements, the following operations were carried out

Firstly, the layered vectorization processing was conducted on the classified NOAA AVHRR image of the Prairie Provinces (Image 2) to extract the vegetation theme and

convert it to a vector format. However, the result is not island-polygon-free data, as shown in Image 21. Considering the physical limitation of the IDRISI vector conversion function (a maximum of about 4000 elements of boundary tracing matrices), Image 2 was firstly split in to 8 window images. The vectorization operation was then carried out on each of the 8 window images. The program <APPEND> developed in the project was used further to joint the 8 vector files of the corresponding window images together into a single vector file. The vectorization of the whole Image 2 data took about 6 hours in a COMPAQ/386 PC computer.

An image classification "noise" handling operation was then carried on the above data so as to filter out these "noises". The program called <EXNOISE> developed in the project was used for this purpose. The "noises", i.e. the white pixels in green background or green pixels in white background in Image 21, were filtered in the process.

The format conversion "noise" was handled further by using the IDRISI built-in function <LINEGEN>. In particular, the low-pass algorithm with 5 point average moving rate was used to process the image.

Finally, an island polygon handling operation was carried out so as to separate the island polygons from non-island polygons and organize them in two different files. The operation was achieved by using the program <ISLAND> developed in the project.

The result was shown in Image 22, where the island polygon (blue color) and non-island polygon data (brown color) have already been organized in two different files, and the data sets have been sent to and used in the EA environment.

In addition to the above transfer in vector format, all raster images in the IDRISI raster

IMAGE 21 A VECTOR FORMAT VEGETATION DISTRIBUTION MAP OF
THE PRAIRIE PROVINCES (WITH ISLAND POLYGONS)

IMAGE 22 A VECTOR FORMAT VEGETATION DISTRIBUTION MAP OF
THE PRAIRIE PROVINCES (WITHOUT ISLAND POLYGONS)

format can be displayed in the SUN workstation. However, in order to display the images in the EA environment, a format conversion, i.e., from the IDRISI raster format to the EA run-length code raster format, needs to be carried out. After doing so, all the 2-D and 3-D, temporal and atemporal images created in the IDRISI environment can be directly used for electronic mapping in the EA system.

9.4.2 Transfer of Thematic Data from EA to IDRISI

The ecoregion boundary data at national coverage with scale 1:7,500,000 were used in the experimentation of transferring thematic data from EA to IDRISI. The data were first organized in the ARC/INFO ungenerated format before the transfer, based on the fact all EA data are actually imported from the ARC/INFO system in the ARC/INFO ungenerated format. The data set was then loaded into the IDRISI system, and a conversion operation from the ARC/INFO ungenerated format to the IDRISI format was carried out on the data. Figure 9.1 presents the data in the IDRISI format. The data can be finally overlaid on remote sensing images to produce synthetic image maps or used in assisting image geometric rectification in the IDRISI system. In the experiment, only boundary data was transferred. The attribute data associated with the boundary data need to be transferred in future if required.

9.5 SUMMARY OF EXPERIMENTS

In summary, the experiments on the image classification, image post-processing, atemporal and temporal image mapping, and data transfer from IDRISI to EA were conducted in the integration.

FIG. 9.1 THE DATA SET TRANSFERRED FROM THE EA SYSTEM (ECOREGIONS OF CANADA)

The results of image classifications show that the Maximum Likelihood approach produces classified data with the highest accuracy, while the accuracy of classified image data from the parallelepiped approach is among the lowest.

The results of image post-processing operations indicate that the IDRISI system and other functions developed (island polygon handling and classification "noise" handling functions) in the project can be effectively used to conduct raster-to-vector format conversion and image classification "noise" handling. However, the handling of format conversion "noise" with the IDRISI system is not satisfactory, because of the sliver polygons resulted from the drawback of the IDRISI vector data structure. Thus, it is recommended that the operation be carried out through the use of ARC/INFO line generalization function.

It was also illustrated, in the image mapping experiments, that the remotely sensed data together with spatial and non-spatial data can be effectively used to create 2-D and 3-D, atemporal and temporal image maps within the integration environment. All the image maps created in the project, in particular those in this chapter, are experimental results, and are only used to demonstrate the feasibility of the related methodologies and operational procedures developed in the thesis. Although they are not specifically related to any realm in the national mapping program, these image maps show us significant potentials or directions of applying remotely sensed data in the national mapping program as new data representation media. Attention should, however, especially be paid to the quality of image maps in applying the related image mapping approaches to the national mapping practice. However, the mechanisms for asynchronical temporal image mapping and for using more patterns, rather than only using color, to represent temporal information are needed to be developed for the further development of the integration.

Two experiments for data transfer from IDRISI to EA have been carried out. One data set used was a vector-based land use map provided by the IDRISI system. The other was a vector-based vegetation distribution map generated from a classified NOAA AVHRR image of the Prairie Provinces. The experiments show that the vector-based classified remotely sensed data provided by the IDRISI system can be transferred to the EA system for electronic mapping applications. The raster-based remotely sensed data from the IDRISI system can be displayed in the SUN workstations at the present time. Examples are the monthly Africa NDVI data derived from NOAA AVHRR images. However, a format conversion, i.e., from the IDRISI raster format to the EA run-length code raster format, needs to be carried out further on raster-based remotely sensed images from IDRISI in order to directly use them in the EA environment. An experiment of data transfer from EA to IDRISI has also been carried out, in which an ecoregion boundary data set was used.

CHAPTER 10

CONCLUSION AND RECOMMENDATIONS

This research has accomplished a feasibility study of integrating remote sensing into the Electronic Atlas of Canada based on the IDRISI system. It is the first attempt to provide a systematic methodology for using remotely sensed data in the national mapping applications in the EA environment. More specifically, the research efforts include the discussion of the potential integration approaches for the specific integration task, the analysis of the necessity of image post-processing in the integration, the development of a set of thematic information classification, image post-processing, and image mapping procedures, the construction of an experimental integration environment, and the accomplishment of a set of experiments to test the integration function developed in the project. The followings present the research steps undertaken and draw specific conclusions:

1. An analysis of the characteristics of the National Atlas of Canada, the characteristics of remotely sensed data, and the potential contributions of remotely sensed data to the national mapping program was conducted. The analysis demonstrates that remotely sensed data and remote sensing image processing techniques can be effectively used in map revision of some topics, monitoring of dynamic phenomena, and new data representation of some topics for the national mapping program. More specifically, remote sensing technology can provide efficient tools in map data revision for the following themes: forest distribution, land use inventory, snow and ice distribution, wetland distribution, glaciers distribution, sea-ice distribution, etc. It can be used in the dynamic monitoring of acid rain, snow and ice coverage, distribution of icebergs, biospheric environment change, flooding and its

impact, agro-climate and diseases, and, forest fire, insect and disease. It can also provide diverse map representation approaches, ranging from atemporal to temporal, from 2-dimensional to 3-dimensional image mapping, from non-synthetic to synthetic, and from continuous-tone to classified image mapping.

2. The basic characteristics of the major environments involved in the integration, namely, the Electronic Atlas of Canada and the IDRISI system were reviewed. This provides a fundamental basis for the development of a proper system integration strategy. The overview illustrates that the IDRISI system, from the perspective of remote sensing image processing, can be used as a basic supporting system for the first level of integration. However, in order to provide users with more flexible integration environments, the image processing capabilities of a supporting system, need to be improved. Two alternatives can be considered in the future efforts. One is to improve the IDRISI image processing functions further, including: image batch processing, system functions for monitoring and controlling image processing processes, the automatic image matching mechanism, mechanisms for high level ancillary information image classification, and filtering mechanisms in the frequency domain. The other alternative is to use a more powerful image processing system as supports for the integration. The further discussions are addressed in the recommendation section.

3. Integration approaches have been addressed based on the present technical capabilities of the Electronic Atlas of Canada and the IDRISI system, and on the advances in artificial intelligence, expert systems and database technologies. There are three potential integration avenues. The first level approach would achieve an integration on the basis of two separate systems (the EA and an image analysis system) which can run on different hardware platforms and in different software environments. This integration level can be achieved through the use of the data exchange format bridging the EA system and an image analysis

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system. The second integration approach would also be based on two systems (the EA and an image analysis system), but their operations must be under the control of a common user interface. This integration level could function more efficiently and more effectively than the first integration level, but it requires that two systems work on the same hardware platform and the same software environment. The third integration approach would be the development of a totally integrated knowledge-based system. The achievement of this integration level would be based on advances in artificial intelligence and expert systems technology. This level of integration would consist of a series of knowledge-based expert systems, including an intelligent spatio-temporal database system, a knowledge-based error handling system, a knowledge-based image analysis system, a knowledge-based statistical analysis system, a knowledge-based map design system and a knowledge-based visualization system.

4. System integration between the EA and the IDRISI systems has been basically achieved on the basis of the first level integration approach. This was conducted following a feasibility analysis of the three integration approaches as they apply to the EA and the IDRISI system. A data exchange format was established through the use of the ARC/INFO ungenerated data format, and an operational data exchange procedure was developed. The tests conducted show that the design and development of the data exchange format achieved the basic criteria of the design, namely, simplicity of data exchange and sharing of spatial data. In order to achieve the goals of the integration, the respective responsibilities of the EA and IDRISI system are defined in detail by taking into account both the data manipulation characteristics and the users' operational efficiencies.

5. Operational procedures for thematic information extraction from remote sensing images for national mapping were developed based on the image classification functions provided by the IDRISI system. The procedures involved include those used for the preparation of

image data and ancillary data, the preprocessing of image data, the selections of training areas, the extraction of signature data, and the assessment of the classification results. The image classification approaches involved in the proposed procedures include one unsupervised classifier and three supervised classifiers (the maximum likelihood approach, the minimum distance approach and the parallelepiped approach). In addition, an operational comparison of the three image classification approaches was conducted, in order to provide users with an operational guideline for image classification processing.

6. The necessity and the methodologies for image post-processing were highlighted in order to provide qualified data for national mapping applications. Based on the analysis of the requirements of spatial data involved in the national mapping program, a set of necessary image post-processing procedures required for narrowing the differences of remotely sensed data and national mapping data were developed. These image post-processing operations include: raster-to-vector format conversion and vice versa, format conversion "noise" handling, national coverage image concatenation, spatial resolution standardization, projection conversion, multi-temporal image matching, and the merging of remotely sensed data with data from other data sources. Other image post-processing mechanisms, such as classification "noise" and island polygon handling which are not available in the IDRISI system, are developed in the project. Using these operations, the data processing gap existing between the remote sensing and GIS domains can be effectively narrowed.

7. A set of atemporal and temporal, 2-dimensional and 3-dimensional image mapping procedures was developed on the basis of the image processing functions provided by the IDRISI system. These image mapping procedures include: 2-D and 3-D non-synthetic and synthetic continuous-tone image mapping, 2-D and 3-D non-synthetic and synthetic classified image mapping, 2-D and 3-D topographic image mapping, 3-D statistical image

mapping, snapshot temporal image mapping, asynchronic temporal image mapping, and overlaid temporal image mapping. These rich image mapping approaches will provide national mapping applications with diverse data representation media.

8. A set of experiments was conducted in order to systematically demonstrate the feasibility of the methodologies and operational procedures developed in the project. These include tests of the functionalities of thematic information extraction from remote sensing data, of image post-processing mechanisms, and of the functionalities of image mapping functions. The experiment results show that the integration is feasible on the basis of the first integration level strategy.

9. Experiments of vector-based data transfer (based on a land use data set provided by IDRISI and the island polygon layer data of the Prairie Provinces classified vegetation image) from IDRISI to EA and vice versa were carried out through the use of the ARC/INFO ungenerated data exchange format. This implementation will allow the EA users to use the remotely sensed data processed by IDRISI, and will also allow the IDRISI users to employ thematic data from EA in image processing.

The theoretical analyses of the potentials of remote sensing in the national mapping program, the development of integration methodologies, and the integration experiments have demonstrated the feasibility of the integration of remotely sensed data and image processing technology into the Electronic Atlas of Canada. Considering the technical conditions of the EA and the IDRISI systems, the concepts of the first level of integration were applied in the integration, and an experimental integrated environment under the concepts has been basically achieved with the support of IDRISI, which provides basic image classification, image manipulation, image input and output, and image format conversion functions. The advantages of this level's integration are: it allows both the EA

and the IDRISI systems running under different hardware and software environment and little change is required with the functionality of both the systems. However, since the two systems are running under different hardware and software environments, users have to interact with two different hardware and software systems. As a result, this may cause certain operational inefficiencies in applications. For instance, several procedures are needed in vector data preparation and transfer from IDRISI to EA.

The overall research and experiments conducted in the project provided researchers who are involved in the integration of remote sensing into GIS with valuable experiences or references in integration methodologies, thematic data extraction from remote sensing images, image post-processing, image mapping, and data exchange between GIS and IAS. In particular, the EA users will be able to conduct integration operations by following the procedures provided in the thesis.

However, the integration can be further improved, especially in the respects of image processing capability and data transfer between related systems. Further efforts can be made in a short term and a medium/long term in order to achieve a more effective and robust integration.

Short Term Development

Remote Sensing Support System

Two alternatives can be considered in the further efforts of improving the image processing capability in the integration environment. The first approach is to enhance the image manipulation capability of the IDRISI system. More specifically, the following functions listed by priority need to be improved, in order to use the system as an image processing supporting system for the first level of integration:

- (1) data manipulation mechanisms, including a mechanism for automatic image matching and a mechanism for image batch processing;
- (2) image processing mechanisms, including basic functions for high level ancillary information image classification;
- (3) image mapping functions, include a function for asynchronous temporal image mapping and a function for overlay temporal image mapping using more patterns;
- (4) raster format conversion function from the IDRISI raster format to the EA run-length code raster format.

The other more effective approach is to use one of the more powerful image analysis systems, such as PCI EASE/PACE, DIPIX ARIES, ERDAS, IFS and ERM. These systems are powerful in image processing in terms of: system capabilities for interactive and batch processing, flexible system user-interfaces, system functions to monitor and control processing operations, capabilities of chaining processing tasks into multi-step jobs, capabilities for automatic cataloging of data sets; and a set of utility programs to handle service functions. By doing so, the supporting system for image processing will be able to provide a more efficient image processing environment for the integration task.

Data Transfer

- (1) Projecting all transferred data into the map projection that is used in the national mapping and transforming them to a proper national mapping scale;
- (2) Displaying both the EA data and the IDRISI data together in the EA environment.

Error Handling

Errors occur in the integrated maps of remote sensing image and EA data, at all integration levels. A module should be developed to handle these problems in the EA environment; expert system approaches may make this more effective.

Medium and Long Term Development

In order to achieve an integrated knowledge-based system, the following expert systems are required in the long term development of the integration of remotely sensed data into the Electronic Atlas of Canada: an intelligent spatio-temporal database system, a knowledge-based error handling system, a knowledge-based image analysis system, a knowledge-based statistical analysis system, a knowledge-based map design system, and a knowledge-based visualization system.

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Appendix Experimental Data Sources

1. NOAA AVHRR Images of the Prairie Provinces of Canada
Band 1 image 1987
Band 4 image
NDVI image
2. National Coverage NOAA AVHRR images
(missing northern territories)
Band 1 image 1987
Band 2 image
3. National Coverage DEM data with 5 km x 5 km resolution
4. National Coverage Water Body data
5. Census Boundary Data of the Prairie Provinces of Canada
6. Political Boundary of Canada
7. Digital Terrain Data - the IDRISI system accompany data set.
8. The Ecoregion Data of Canada

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