A Method for Integrating Remote Sensing and Geographic Information Systems

Qiming Zhou
School of Geography, The University of New South Wales, P. O. Box 1, Kensington, NSW 2033, Australia

ABSTRACT: A Relational Image-based Geographic Information System (RIGIS) has been developed for interfacing geographic information and remotely sensed data for land resource studies in the arid zone of Australia. The system is composed of two interrelated subsystems: an image database which handles spatial data sets, such as topography and Landsat imagery, using spatial modeling techniques, and an aspatial database which handles attribute data relating to these spatial data coverages. A relational model has been employed for database management, and interfaces have been developed to allow a high-level view by the user of the spatial and aspatial entities. The paper describes the design of the RIGIS software implementation, named MAP/INFO*, and its application to land resource studies using digital remotely sensed data as well as geo-based data sets. The integration of such data sets for arid land studies is discussed.

INTRODUCTION

EFFECTIVE UTILIZATION of large amounts of remotely sensed data is dependent upon the existence of an efficient geographic handling and processing system that will transform the data into usable information for decision-making activities. Such a system should provide the following capabilities:

- reduce redundancy and the inconsistency of data stored,
- provide the integration of various data (including remotely sensed data) for specific purposes,
- promote ease and efficiency in updating data storage, and
- provide capabilities for querying databases to present geographic information which is not directly available from original data sets.

The major tools for handling spatial data are geographic information systems (GIS). These are ". . .designed to accept large quantities of spatial data derived from a variety of sources,. . .and to efficiently store, retrieve, manipulate, analyze and display these data according to user-defined specifications" (Marble and Peuquet, 1983). Many GISs have been constructed, but the majority of these systems are vector-based and designed to use data derived from sources other than satellite imagery. Digital remotely sensed data are not typically included in such GISs due to the incompatibility of their raster data structure and statistical processing concepts.

An alternative approach is to use a raster structure which is directly compatible with digital remotely sensed data. The concept behind the development of an Image-based Geographic

*The software name, MAP/INFO, is derived from MAP modeling system and INFO relational database management system. The name is for the research purpose only and has no relation to the registered trademark "MAPINFO" of Mapinfo Corporation, Troy, New York.

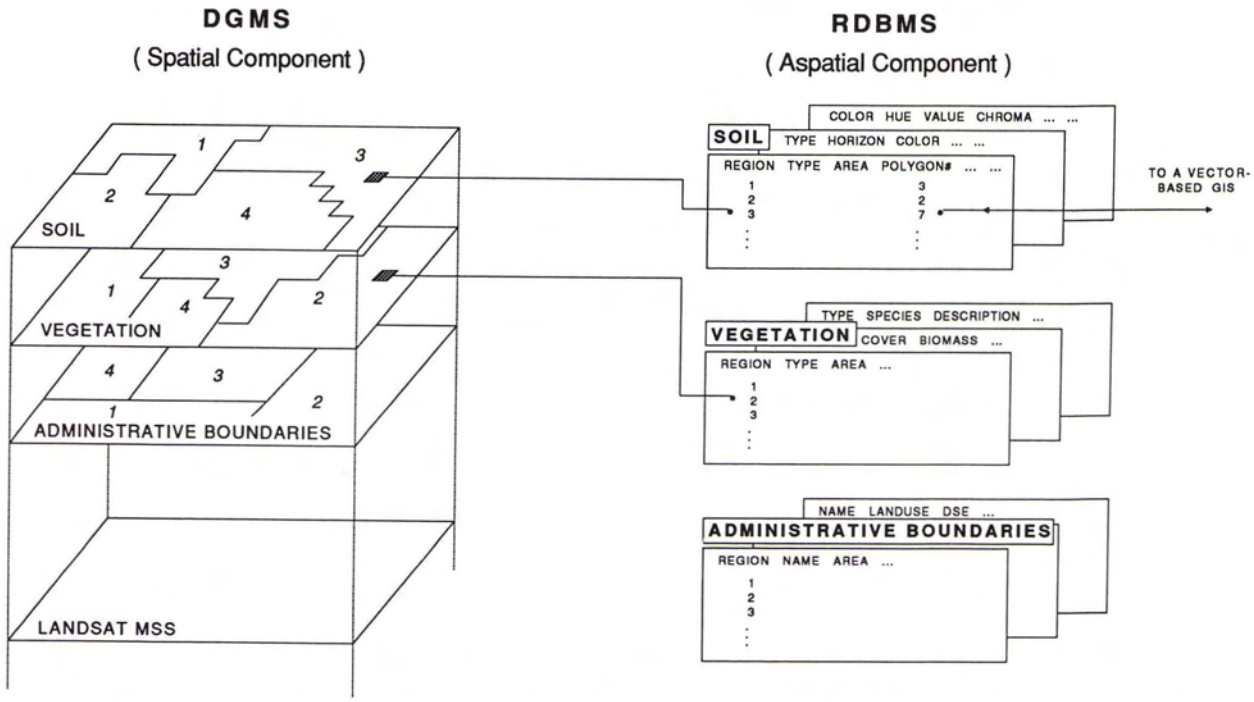

FIG. 1. Spatial and aspatial components of a Relational Image-based Geographic Information System and their internal relationships.

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Information System (IGIS) initially grew out of an Image-Based Information System (IBIS) described by Bryant and Zobrist (1976, 1981). Other systems have been developed based on remote sensing image processing technology for a variety of purposes (Bartolucci *et al.*, 1983; Graetz *et al.*, 1982). These systems, however, emphased image processing techniques, even though they did contain a number of powerful GIS capabilities. Alternatively, raster-based systems have also been developed based on more traditional geographic modeling techniques (Tomlin, 1983; Olsson, 1985; Berry, 1987). These systems have generally tended to emphasize spatial data transformation and modeling, rather than database management and data retrieving.

Recently, significant efforts have been made to develop techniques incorporating vector and raster geographic information (Maffini, 1987). One remarkable development is the recent research in linking IBIS with a CAD/CAM system (Logan and Bryant, 1987). With this linkage, vector thematic information can be captured by the CAD/CAM system and then manipulated in the IBIS, while raster data can be converted into vectors which can then be output through the CAD/CAM system. Tabular data which records attribute information of its corresponding spatial data entities are stored in a form called "interface file" and can then be used for producing a thematic map.

From a GIS point of view, the above developments have significantly enhanced system capabilities in terms of integrated data processing and transformation. Problems exist, however, in obtaining a well-organized data base management system (DBMS) which can adequately handle both the spatial and attribute entities of the database, in designing appropriate data interfaces which allow efficient cooperation between vector and raster data sets, and in applying a user-friendly query language by which practical geographic models can be built.

To meet these requirements, the research outlined in this paper focuses on developing MAP/INFO — a software system implementing a relation image-based geographic information system (RIGIS). The system is built on the top of a conventional relational data base management system (RDBMS) and a raster-based spatial modeling system, but has a strong linkage to vector-based GIS software. Using this system, geographic information can be digitized and edited using the vector-based GIS and then be converted and processed under a raster-based environment together with remote sensing images. On output, "hybrid" (i.e., a mixture of image-based and vector-based) graphics can be generated according to the user's specification.

A RELATIONAL IMAGE-BASED GEOGRAPHIC INFORMATION SYSTEM

Geographic information, derived from thematic maps, ground investigations, or government statistical databases (e.g., Census), commonly contains more than one attribute associated with its spatial location. Remotely sensed data, on the other hand, have only one attribute (i.e., a digital value which records, for example, ground brightness, vegetation index, or a code for a classified theme) associated with each data coverage. In integrating data from both geo-based sources and remote sensing, the above difference in data characteristics must be taken into account. Thus, conceptually the database entities of a RIGIS are separated into spatial and aspatial components. The spatial component can be defined as a raster-based database system or, in other words, an image-based database. The aspatial component can be defined as a normal relational database such as is commonly used in commercial applications. Interfaces have been developed to link these spatial and aspatial component for geographic applications.

In the image-based database, the RIGIS stores indexed region codes or spatial indices in each data plane instead of storing the actual cell values. The spatial indices are then used as the key items in corresponding aspatial entities. The associated attributes are stored in the aspatial component of the database as a multi-attribute record in a relational table for each spatial index. A similar approach has been implemented by the IBIS' "interface file" (Logan and Bryant, 1987) by which each image value has been stored as an index of a tabular record. Different from the IBIS' approach, however, RIGIS defines one or more relational tables which are handled by a conventional RDBMS, instead of a simple tabular database entry (Figure 1). Using the RDBMS, spatial operations such as image value recoding, and calculation of density and change rate in the raster data processing can be simply converted into relational operations. Thus, only a few records in the relational table need to be processed, and results can be recorded as new attributes of these records. These new attributes can be recalled later by referencing the region codes for further spatial operation or display.

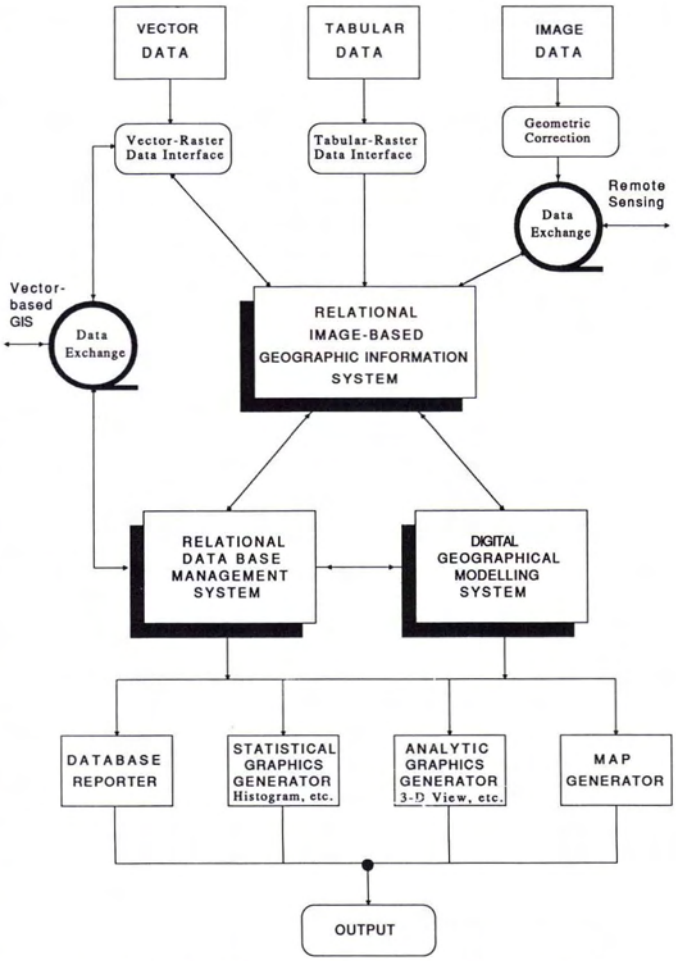

FIG. 2. Configuration of the MAP/INFO software system.

Two access methods can be utilized in spatial data retrieval operations. The first follows traditional raster-based information systems and defines a window based on geo-referenced identifiers. The information relating to the grid cells which fall within a particular window can then be retrieved from the aspatial database through the spatial indices. The second method uses the relational query process to retrieve records which satisfy the specified qualifiers. The grid cells related to these records can then be retrieved from the image-based database using the spatial indices in these selected aspatial records.

THE MAP/INFO SOFTWARE SYSTEM

The current implementation of the RIGIS is the MAP/INFO software system which has been developed in the School of Ge-

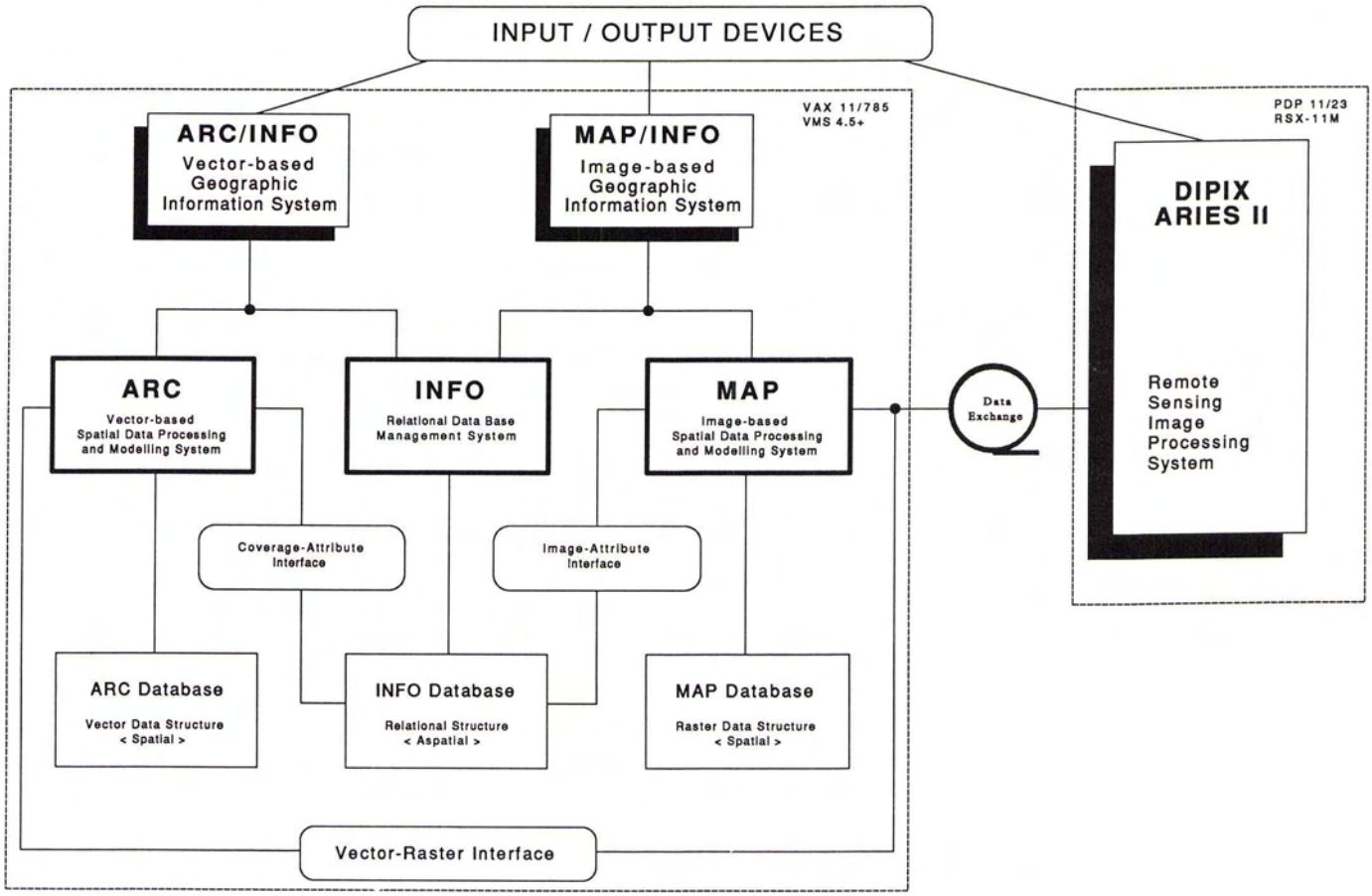

FIG. 3. The integration of GIS and remote sensing-the MAP/INFO environment at UNSW.

ography, the University of New South Wales, Australia (Zhou, 1987). A complete RIGIS should include both computer hardware and software systems. However, for the research outlined here, only the software systems and their operating environment are discussed.

SYSTEM CONFIGURATION

The core of the MAP/INFO configuration is composed of three major software components: an RDBMS, a digital geographic modeling system (DGMS), and an operating shell on top of the two systems (Figure 2). Functionally, the system contains four major subsystems: data input and preparation, database management, data manipulation, and report and data display. However, each of the subsystems is configured to satisfy the special requirements for integrating geographic information and remotely-sensed data.

The most significant difference between MAP/INFO and other image-based GIS is its dual database system configuration. With this configuration, the spatial components of the data are stored in the form of multiple layers of images, while the corresponding aspatial components are stored as relational tables. The DGMS is employed to handle the spatial entities of the database based on raster spatial modeling techniques. Aspatial data, on the other hand, are handled by a normal RDBMS which is no different from most business-oriented systems. Both data and instructional interfaces have been developed between the two database systems, and internal data flow is bi-directional. Thus, the database entities can be retrieved and updated through the modeling system according to user's spatial query, or through the RDBMS according to the user's relational query.

The DGMS of the MAP/INFO originates from a digital cartographic modeling system named Map Analysis Package (MAP), initially developed at Yale School of Forestry and Environmental Studies (Tomlin, 1983) and subsequently modified and expanded at the University of New South Wales. The entire MAP software has then been re-written to implement RIGIS conceptual framework. The RDBMS of the MAP/INFO employs a commercial software system named INFO, developed by Henco Software (Henco Software, Inc., 1984). In fact, the MAP/INFO operating shell and interfaces between MAP and INFO have been written in such a maner that other relational DBMS packages can be easily adopted instead.

As shown in Figure 3, a fully operational integrated system includes a vector-based GIS, an image-based GIS, and an image processing system. The ARC/INFO software system (Environmental System Research Institute, 1986) has been used as the vector-based GIS. Geographic information can be captured from analog maps and edited within ARC/INFO in the form of vectors and then converted and transferred to MAP/INFO through a vector-to-raster interface between the ARC and MAP spatial database systems. The RDBMS INFO is used by both ARC/INFO and MAP/INFO for attribute data handling; therefore, the aspatial information is virtually sharable by both the vector and raster systems. A DIPIX Aries II Image Processing System provides image processing capabilities for the RIGIS operating environment. Raster-based data can be exchanged between the RIGIS and DIPIX through data exchange utilities.

In between the ARC/INFO and DIPIX, MAP/INFO performs as a bridge linking the vector-based information and raster-based

remotely-sensed data. Data can be input to MAP/INFO from both the vector-based GIS and remote sensing image processing system. Manipulated data can be directed to the output devices to generate a graphics display together with vector features which can be directly retrieved from the ARC database, or to either the vector-based GIS or image processing system. Statistical graphics and analytical graphics, such as perspective views of three-dimensional surface, can also be generated using MAP/INFO's graphics output routines.

User's Interface

The command syntax of MAP/INFO operations is designed as an English-like fourth-generation language which assumes no prior experience in computer programming. The language has been developed based on an enhanced version of Map Algebra described by Tomlin (1983) and a relational query language. As far as the user is concerned, use of the MAP/INFO system is in many ways similar to the use of traditional techniques involving conventional geographic maps and relational database management. For example, the command

DESCRIBE PADDOCKS WHERE "SHEEP > 100" STATISTICALLY

displays statistical information for paddocks where the current sheep population is greater than 100; while the command

SHADE TOPOGRAPHY ON 5-APR-1987 AT 9:05-
FOR SHADING__IMAGE

creates a new image data coverage named "SHADING__IMAGE" which emulates the shade by the sun over a digital elevation model at the specified date and time.

All the basic functions and operations may be flexibly combined into a variety of more complex procedures or macros to allow the construction of more complicated spatial models.

THE PRELIMINARY APPLICATION

The application of the MAP/INFO system is currently being undertaking at the Fowlers Gap Arid Zone Research Station in western New South Wales, Australia. The station is located 110 kilometres from Broken Hill at the northern extremity of the Barrier Range. A detailed discussion of the local environment can be found in Mabbutt (1973). The major objective of the application is the analysis of land degradation problems on the station based on monitoring native land-cover change using remote sensing and modeling land resource consumers, such as sheep and kangaroos, using the digital database.

Construction of the digital geographic databases of Fowlers Gap Station commenced in 1986 (Milne and Zhou, 1986) and is being continued. These databases based on 50-by 50-metre and 25-by 25-metre grid cell sizes are designed so as to merge and integrate remotely sensed data such as Landsat MSS and TM and geo-based data. The UTM map coordinate system is used as basic geometric reference system.

Four categories of data-background information, thematic information, topographic information, and image information-have been introduced to establish a comprehensive database for land resource research. The *background information* includes historical records on climate, vegetation, land administration, and wildlife population. This type of information provides general environmental characteristics for the overall study area and land-use features for individual land administration units such as paddocks. The background information is available in a tabular form and can be directly input to the INFO RDBMS. The *thematic information* includes paddock boundaries, land systems, vegetation types, etc. Information of this kind is at the nominal level of measurement and represents non-continuous surfaces. The thematic information was digitized and edited using ARC/INFO and then converted to the MAP/INFO database by the direct overlay method. The *topographic information* is available in the form of contour maps. Based on the assumption that the contour lines represent a smooth, continuous, three-dimensional surface, the elevation sample points were digitized and converted into a digital elevation model (DEM) through the MAP/INFO vector-to-raster data interface using an interpolation method. The available *image information* includes Landsat MASS and TM data. The remotely sensed information has been directly input into the spatial databases after geometric registration and resampling using the DIPIX image processing system.

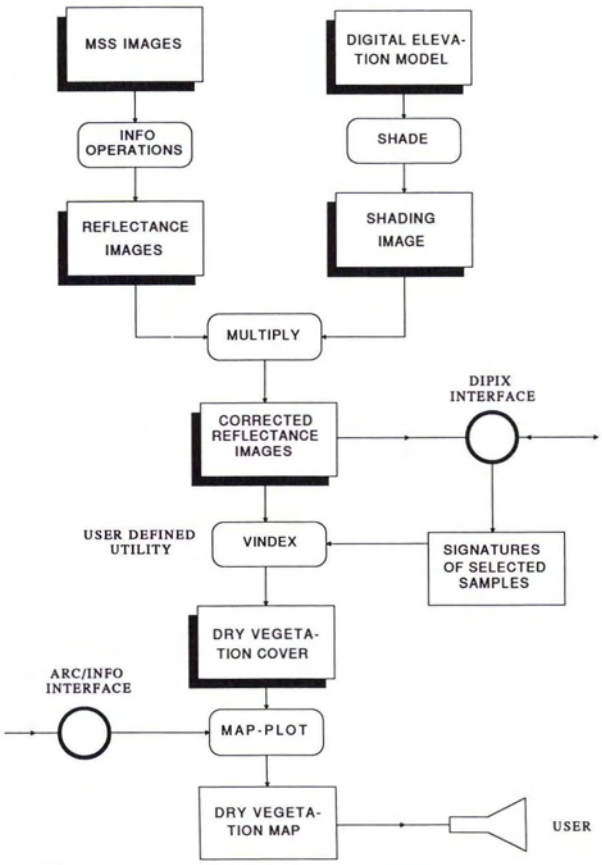

FIG. 4. The conceptual model of dry vegetation cover using the MAP/INFO system.

Using the data from various sources, spatial models are being developed for land resource studies at the station. In a preliminary arid zone vegetation study, a dry vegetation cover model has been created using Landsat MSS images and a digital elevation model. The conceptual model is shown in Figure 4 and the practical process can be described by the following steps:

(1) *Radiometric correction and transformation of Landsat MSS images.* The MSS images were transformed into percentage reflectance using Forster's method (Forster, 1984). This correction was achieved mainly using INFO relational operations, and resulting reflectance values were stored as a new attribute for each raw digital number of the image.
(2) *Creation of a shading image from a digital elevation model.* The percentage reflection of sun rays for each grid cell was calculated according to the sun location at the Landsat passing time and slope aspect using MAP/INFO's "SHADE" function.
(3) *Topographic correction of the MSS images.* The reflectance images created in step 1 were overlapped with the shading image created in step 2 to eliminate the shading effect over the ground surface using INFO operations and MAP/INFO's "DIVIDE" operation.

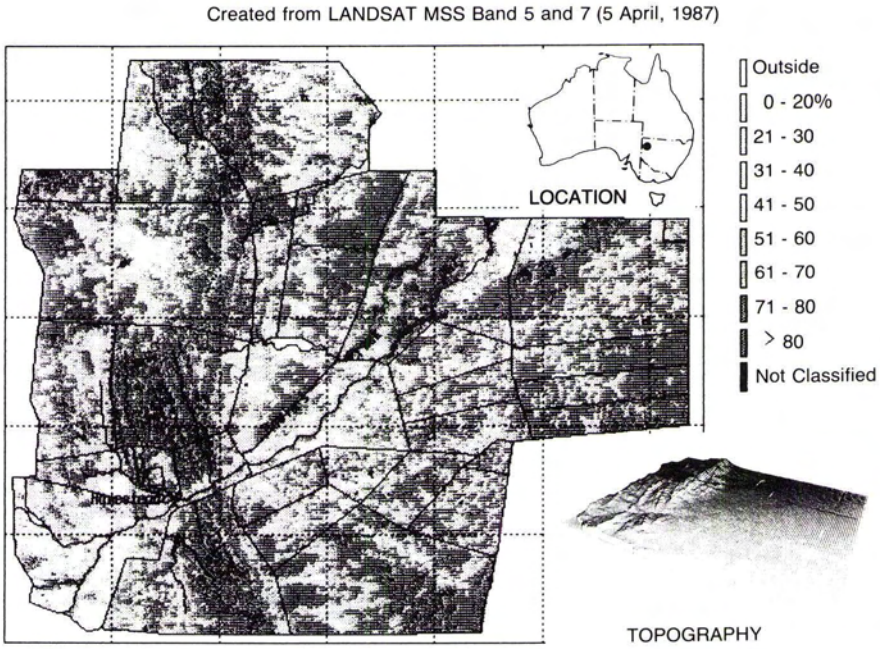

FIG 5. The graphics output produced by MAP/INFO showing percentage dry vegetation cover over the study area.

TABLE 1. TABULAR OUTPUT SHOWING PADDOCKS IN FOWLERS GAP STATION WHERE AVERAGE DRY VEGETATION COVER IS LESS THAN OR EQUAL TO 55 PERCENT

Paddock	Percent Cover	Cells	Percent Area
Gap Creek	42	8544	3.7
Saloon	45	5519	2.4
Mating	47	1622	0.7
Hotel	48	3728	1.6
Mandleman	51	11114	4.9
Salt 1	51	2723	1.2
Strip Holding	51	2247	1.0
Conservation	52	2111	0.9
Emu	52	148	0.1
North Warrens	52	2518	1.1
Gap Hills	53	11088	4.8
Salt 2	53	2243	1.0
South Sandstone	53	5653	2.5
Bald Hills	54	6950	3.0
Homestead	54	31	0.0
Salt 3	54	2444	1.1
Sandstone	54	15263	6.7
Gorge	55	2569	1.1
Total		86515	37.8

(4) *Creation of a dry vegetation cover image.* A dry vegetation cover image was created using Pech's algorithm (Pech *et al.*, 1986). To achieve this, the corrected MSS data created in step 3 were transferred to the DIPIX image processing system to create spectral signatures on the maximum dry and green vegetation cover and bare soil. The signatures were then used as the reference points to transform the spectral reflectance of MSS band 5 and 7 to the percentage dry vegetation coverage using a user-defined utility (VINDEX) in MAP/INFO.

(5) *Plotting Results.* A lookup table was created for displaying the resulting dry vegetation map as a new attribute in the corresponding relational table. The coverage was displayed and plotted on a graphics output device and superimposed with vector information which is directly retrieved from ARC/INFO (Figure 5).

Within the MAP/INFO environment, spatial and relational queries can be addressed. In this preliminary study, a tabular summary (Table 1) was created to select all paddocks where dry vegetation cover is less than or equal to 55 percent using both spatial and relational queries such as

AGGREGATE DRY__VEGETATION OVER PADDOCKS-
USING AVERAGE FOR AVERAGE__COVER
DESCRIBE AVERAGE__COVER WHERE "COVER LE 55"

Using the RIGIS technology, more useful information for the land manager can be obtained from the existing database to establish a real-time land management system. Further research is anticipated in the station for developing spatial models on vegetation cover change, land evaluation, and land degradation.

CONCLUSION

MAP/INFO has been designed to specifically integrate remote sensing with geo-based data sets. In land resource studies, it is commonly required that the data from both sources can be processed together in order to obtain spatial information for better land management. This can be achieved by setting up a RIGIS under the MAP/INFO environment.

Geographic modeling techniques are employed for data manipulation and transformation. The capabilities of the system, however, are largely improved by adopting an RDBMS as a kernel for handling aspatial components relating to each geographical region. A flexible user query interface is provided by MAP/INFO system to make it possible and easier to establish more complicated models.

Further research will address issues concerning high-level geographic models, remote sensing data transformation and classification by introducing geo-based data, spatial query processes, and user interfaces on the RIGIS workstations.

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