GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING: TOWARDS THE BETTER INTEGRATION OF DATA FOR LAND RESOURCE MANAGEMENT*

Q. Zhou and B.J. Garner
School of Geography
The University of New South Wales

ABSTRACT

The value of geographical information systems and remote sensing as tools for land and resource management is now widely recognised and their application well documented. Better integration of the technologies offers the potential, however, for developing more powerful and useful tools for land and resource management. This paper focuses on the integration of image data with geographical information systems and reports on the development of a prototype relational image-based geographical information system and its application to land and resource management in the semi-arid zone of Australia.

INTRODUCTION

Geographical information systems (GIS) and remote sensing are well-established information technologies, the value of which for applications in land and natural resources management are now widely recognised. They are, however, still essentially separate technologies and practitioners still generally consider themselves primarily involved with one or the other. This is explicitly recognised in "definitions of the fields", a concern with different sets of tools, problems, and procedures as well as separate professional identifies and orientation in the scientific community. This notwithstanding, it is becoming increasingly apparent that remote sensing and GIS do not stand in isolation but are part of a larger entity concerned fundamentally with handling and analyzing geographical data in which neither is dominant (Fisher and Lindenberg, 1989). As Ehlers et al. (1989) have argued, "the more or less separate GIS and remote sensing communities have to accept that both need each other (and) the integration of these technologies will inevitably lead to a synergistic approach to spatial data handling". Integration of the technologies per se is, however, still a long way off, even if it can be argued that it is necessary, and is hindered by technical, institutional, even educational limitations.

ON INTEGRATION

For all intent and purposes, the current state of integration of remote sensing and geographical information systems can best be described as task oriented. Cartographic data from GIS in various forms is increasingly used to enable better analysis and classification of image data, albeit often as an end in itself. Problems, however, exist which prevent further integrated applications by feeding geographical data into remote sensing systems. These include:

* The complexities of the GIS environment have been poorly understood by remote sensing analysts and systems optimised for remote sensing data processing often have limited GIS capabilities.

* The lack of a Data Base Management System (DBMS) causes severe problems of data redundancy and inconsistency. This also makes attribute data manipulation such as relational retrieval and update extremely difficult within an image processing system environment.

* Typical remote sensing systems do not have the capability to handle data obtained at low levels of measurement. For example, it is very difficult, if not impossible, to handle non-numerical information using an image processing system.

* Traditional image processing systems do not support geographical modelling operations, for example, digital terrain models, landform analysis, potential zone analysis, etc.

In recent years there has been growing awareness of the potential GIS offers for incorporating enhanced image data with geographical data bases, especially for applications directed at process dynamics and the detection and monitoring of spatial change (see, for example, Jadowski and Ehlers, 1989; Nellis, et al., 1990). This becomes particularly important for problems in which real-time or frequently updated information is required for monitoring purposes as in rural land use analysis. A good example, and one pertinent for this discussion, is the monitoring of rangeland resources for which up-to-date information about the state of vegetation cover and biomass is crucial. For these kinds of applications however, it is now apparent that the simplistic linear model of the relationship between remote sensing and GIS, in which the former merely feeds data to the latter, is insufficient. To fully exploit the potential of integrating remote sensing and geographical information systems, a more complex model based on the symbiosis of the two is more appropriate. As means of achieving this the development of Image-based GIS (IGIS)
has become a significant area of recent research in the integration of the two technologies.

**IMAGE-BASED GIS**

An IGIS has three basic characteristics which distinguish it from other typical GIS. Firstly, IGIS is a geographical information system and not a remote sensing image processing system, hence it necessarily includes geographical data handling and manipulation capabilities. Secondly, IGIS is raster-based and therefore fully compatible with remote sensing images and data processing techniques employing raster algorithms. Thirdly, IGIS includes efficient data interfaces for converting vector data to a raster structure, for exchanging geographical information, and for displaying results in both cartographic and photographic forms. An IGIS consequently links traditional geographical information system and remote sensing technologies through a 'two-way' link in which the data flow is bi-directional between them. Within the IGIS environment, geographical information can be transferred to an image processor and processed with remotely-sensed data to improve classification accuracy. Both raw and enhanced remotely-sensed data as well as the results of image classification can also be transferred from the image processor to IGIS for more complicated geographical modelling using raster algorithms. Geographical information from a vector-based system, on the other hand, can be converted into raster format and input to the IGIS. The results of geographical modelling from IGIS can also be converted to a vector format and fed back to the vector system.

The concept for IGIS initially grew out of the Image Based Information System (IBIS) developed in the Jet Propulsion Laboratory (JPL), California Institute of Technology (Bryant and Zobrist, 1976). IBIS, built upon an existing image processing system called the Video Image Communication and Retrieval system (VICAR) was, however, essentially image-processing oriented (Marble, 1980; Zobrist and Nagy, 1981) even though it did contain a number of capabilities of a GIS. Building on this prototype, further development of IGIS has been reported by Graetz, et al. (1982), Bartolucci, et al. (1983) and Logan and Bryant (1987). These were also based on image processing techniques, but incorporated additional GIS capabilities and provided interfaces to vector data. At the same time, raster-based systems were also developed based on more traditional geographical modelling techniques (Tomlin, 1983; Olsson, 1985). Attempts have also been made to define and implement fundamental operations to provide a coherent and flexible basis for a range of spatial modelling applications (Berry, 1987). These systems emphasised spatial applications using 'social physics' (Olsson, 1985) and 'cartographic modelling' (Tomlin, 1983) techniques. The focus was,
however, more on data transformation than data base applications in these systems.

Although these developments have significantly enhanced capabilities in terms of integrated data processing and transformation, their application is limited because of the lack of a well-organised Data Base Management System (DBMS) which can adequately handle both the spatial and attribute entities of the data base. Problems also persist in designing appropriate data interfaces which allow efficient integration of vector and raster data sets, and in applying a user-friendly query language to enable practical geographical models to be built using raster, vector and attribute data.

**RELATIONAL IMAGE-BASED GIS**

To overcome the limitations of IGIS in efficiently integrating geographical and remotely-sensed data, a Relational Image-based Geographical Information System (RIGIS) is proposed, a prototype of which has been developed recently by Zhou (1989a, 1989b). This system is built on raster-based spatial modelling and conventional relational data base management techniques (Codd, 1970, 1982; Date, 1986). It has been designed around a data structure in which both the spatial and attribute information can be efficiently handled through a 'spatial index' which links the spatial and aspatial data entities in the geographical data base. Using this architecture, attributes related to a particular spatial location can be easily retrieved from the relational data base, and spatial locations can also be selected using relational queries on the attributes. Since the attribute information is stored in a relational data base it can be processed using a relational query regardless of whether it links to a raster or vector system. The RIGIS provides the following benefits in accessing and manipulating the integrated geographical data bases:

1. The attribute information can be shared by both raster and vector systems so that the data redundancy is significantly reduced;

2. Many raster-based data processes can be converted into a series of relational data processes so that spatial data processing, which normally requires more system resource, can be minimised;

3. Data originality and accuracy can be maintained by reducing vector-to-raster or raster-to-vector data conversions; and

4. More powerful data processing capabilities can be developed based on both spatial data modelling and relational data base management technologies.
The RIGIS has been implemented by a computer software system named ReMAP which has been developed in the School of Geography at the University of New South Wales. The potential advantages of using this approach to integrating remotely sensed data with GIS can be illustrated by case studies that have been conducted in the applications of the system to rangeland management in Arid Australia.

**SMALL AREA BIOMASS STUDIES AND LAND MANAGEMENT**

The aim of this application was to assist land management at the University of New South Wales' arid zone research station at Fowlers Gap. The station covers an area of about 39,200 hectares and is located 110 kms north of Broken Hill in the western New South Wales. The research station is run on a day-to-day basis as a commercial sheep farm.

During the past 20 years the station has been used by researchers from a variety of disciplines. As a result, research conducted at the station has provided a very good understanding of the bio-physical processes operating in arid environments. Importantly, the station has maintained very good records based on this research and on its commercial operations which provide the necessary statistical data bases required for time-space modelling using GIS. However, from the view point of land management, the results of scientific research need to be interpreted and integrated in a more practical way for "real world" applications. For example, although it is now well established that vegetation cover and biomass vary with annual and seasonal rainfall, the land manager needs answers to more specific questions, for example:

* What is the current status of vegetation in the eastern paddocks and what is the current vegetative productivity there?

* Has the vegetation in a particular area improved or deteriorated over the last three months? Is such change related to rainfall or to overgrazing?

* To what extent can grazing continue without causing land degradation or wastage of resources? In other words: with the current rainfall status, how many sheep can be put into particular paddocks and for how long?

In order to answer these kinds of questions, an Arid Land Resource Management System (ALARMS) has been developed using the RIGIS concept to assist land managers to make decisions (Zhou, 1989b, Zhou and Garner, 1990). This system consists of two major components - an integrated data base and a set of spatial models. The integrated data base comprises spatial and attribute data collected
from previous and present environmental research, the
station's statistical records, and also images from
remote sensing. The theories and methodologies developed
in previous and present research at the station form the
basis of the spatial models in the system. The output
from ALARMS provides information to assist the decision-
making process in real world land administration as well
as providing data source for other research activities.

A major component of this application is based on
detailed studies of vegetation at the station based on
high-resolution remotely-sensed data including Landsat
MSS and TM. Spatial models have been developed to
describe the relationships between a variety of
environmental factors such as landform, vegetation, soil,
weather conditions and land use. A complicated spatial
modelling system has been developed to monitor the
balance between supply and demand of vegetation resources
for each paddock on the station (Figure 1).

ALARMS illustrates an approach to the integration of
detailed geographical information and high-resolution
remotely-sensed data. Models developed focus on the
accuracy of the results based on intensive data
collection and processing. Using the ALARMS data base and
the ReMAP software, spatial modelling operations,
theories and principles derived from more traditional
geographical research can be technologically applied to
"real-world" land management activities. With its
demonstrated capabilities of incorporating remotely-
sensed data with GIS spatial modelling operations, the
system also provides the potential for "real-time"
assistance for decision-making activities in rangeland
management.

**REAL-TIME LAND MANAGEMENT
AT THE REGIONAL SCALE**

The methodology in this study is technically an extension
of that used in above application. The purpose is to
apply the spatial models and methodologies developed in
the small area to regional-scale applications. In this
application, focus is on large area and real-time
problems for which lower accuracy is required than in the
small area applications (Zhou and Milne, 1990).

The study area encompasses some 15,000 square kilometres
in southwestern New South Wales and corresponds with the
area shown on the Poocarcie 1:250,000 Map Sheet. The
major land use activity in the region is sheep and cattle
grazing with current stocking rates ranging between 1
sheep to 4 hectares to 1 sheep to 11 hectares.
Overgrazing, the clearing of selected areas for
cultivation, fire and the invasion of woody shrubs on
marginal land comprise the major threats to environmental
conservation causing both qualitative and quantitative
declines in land surface condition.
Compared to Fowlers Gap, the geographical data from analogue and statistical sources is much less extensive so that the GIS application to land management heavily relies on remotely-sensed data. For large area applications, it is more important to make use of the more frequently updated "real-time" information than it is for small areas, therefore the spatial models developed for this study have been focused on the maximum use of "real-time" data sets such as low-cost remote sensing images and weather records with limited supply of somewhat difficult-to-get geographical information and more expensive high resolution remote sensing images.

The overall structure of the spatial models is outline in Figure 2. As shown in the figure, the input to the spatial models include thematic information such as land systems, geology, property boundaries, roads, residential sites and remotely-sensed data. Among these, the thematic information can be considered as "static" which rarely changes in the time scales associated with rangeland management. Weather records and information derived from remote sensing systems can be considered as "dynamic" providing real-time data for change analysis. The purpose of the spatial models is to integrate the "static" and "dynamic" components in order to describe what is happening to land cover, how it has changed, how it is likely to change and what environmental and human factors are responsible for the change. Based on these descriptive models, the near real-time information can be derived by updating the "dynamic" data components on a regular basis.

The goal in developing this image-based GIS further is to be able to invert the spatial models developed so that range conditions can be predicted from real-time satellite and meteorological data. The real-time applications can also feed back to the system to improve the spatial models. Using this system, near real-time advice can be provided on a region-wide scale for the land manager to assist rangeland management, hazard control and environmental planning.

**CONCLUSION**

This paper has attempted to provide an example of one way in which the better integration of data from remote sensing with geographical information systems can be achieved. It is recognised, however, that the prototype system discussed here represents only one out of many alternative ways of solving the integration problem. Nevertheless, its preliminary application has demonstrated its potential usefulness as an approach to, and as a powerful tool for, land and resource management. It is believed that the approach adopted here represents a significant attempt to improve ways of integrating remotely sensed data into geographical information systems which overcomes some of the obstacles to
integration inherent in the different data structures of the two technologies.

REFERENCES


Bryant, N.A. and A.L. Zobrist (1976), "IBIS: A geographic information system based on digital image processing and raster data type", in 1976 Machine Processing of Remotely Sensed Data Symposium, Purdue University, 1A1-1A7.


