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IBIS: A GEOGRAPHIC INFORMATION SYSTEM BASED ON DIGITAL IMAGE PROCESSING AND IMAGE RASTER DATATYPE

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ABSTRACT

There is a pressing need for geographic information systems which can manage spatially-referenced data, that perform certain types of spatially-oriented processing, and that are current and comprehensive. Polygon overlay and grid cell information systems access data for selected areas, but their data files are time consuming to generate and frequently costly to process. Updating of land use changes for such systems may become prohibitively expensive. In response to the present dilemma, a system is presented that makes use of digital image processing techniques to interface existing geocoded data sets and information management systems with thematic maps and remotely sensed imagery. The basic premise is that geocoded data sets can be referenced to a raster scan that is equivalent to a grid cell data set.

Several technical problems have been overcome to achieve a workable system. First, digital image file handling, image manipulation, and image processing capabilities must be provided. Second, image data must be registered or indexed to spatially-referenced tabular data so that processing steps which involve both types can operate. Third, a data interface must be provided between the different datatypes so that the results of processing can be represented. Finally, image processing analogs must be developed for existing geo-base file computational steps (e.g., overlay, aggregation, cross tabulation, etc.). The system is now in use on a test basis.

INTRODUCTION

Geographic information systems should satisfy four basic criteria if they are to be useful: 1) They should provide specific point locations, as well as area locations of data; 2) They should provide for variable aggregation (sub-setting) of data; 3) They should provide a method for representing spatial arrangements; and 4) They should be able to interface with mathematical and statistical programs which can be called as needed to aid in the analysis of spatially-oriented data.[1] Practitioners of the art of geocoded systems design have progressed with varying degrees of success towards the goals outlined. As a rule, generalized systems have only rudimentary data manipulation capability (i.e., status updating and interrogation by area), while highly specific and specialized systems have progressed further with modelling applications.[2]

In response to the desire to access data for selected areas, polygon and grid cell geocoded information systems have been developed. Such systems rely on the tabular formatting of the input data, a costly and time-consuming process. Often the system falls into disuse because the updating of major segments of the data base becomes prohibitively expensive. In response to the desire to provide up-to-date resource information, investigators have studied the feasibility of applying LANDSAT and high altitude photo imagery to natural resource mapping. The consensus which appears to be evolving is that, while remotely sensed imagery can provide timely coverage and sufficiently accurate maps using ADP techniques, the end product is still a map that cannot interface directly with an existing geocoded information storage and retrieval system.[3]

It has become apparent in working with earth resources images and experimenters that certain system improvements are necessary for the efficient processing of such data. The areas particularly needing improvements are: interactive processing, geocoordinate data entry for map/picture registration, and multispectral classification. Both geographic information system and thematic mapping technologies have in part suffered from a lack of broader application because of constraints to either data input/output or an inability to interface with other types of mapped phenomena. The use of image processing technology to resolve this dilemma was proposed by Billingsley and Bryant in June 1975, and it is the purpose of this paper to report on the development of an Image Based Information System.[4]

To date, software has been developed to generate tabular data sets from image and graphical data sets. Specifically, a data interface has been provided between the different data types so that the results of processing can be represented, and image processing analogs have been developed for existing geo-base file computational steps (i.e., overlay, aggregation, cross tabulation, etc.). The system was applied first to a synthetic test case and has since been applied to several actual cases. The long range objective is to develop and implement the software needed for a geocoded information system facility. The system will make use of digital image processing technology to: a) interface remotely sensed data with other spatially referenced information, and b) perform interactive data base storage, retrieval and analysis operations. The system will provide both rapid up-to-date information access for users' models or the construction of thematic maps, as well as an inexpensive and flexible mode of primary input. The data base design will incorporate the interfacing of tabular and graphically formatted geocoding systems already in existence with an ongoing development of a raster scan formatted geocoding system. The first applications have been restricted to the design of a land resource inventory and analysis system. It is anticipated that the algorithms and hardware interfaces developed will be readily applicable to other LANDSAT applications.

INTERFACING GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING DATA

Data Management Considerations

The ease with which an agency can establish a geographic information system is constrained by the level of detail and the computer technology available. With geocoded data, there is a dramatic increase in file size with every added variable and increased resolution. Thus, a parcel level system for the City of Los Angeles consists of over 800,000 records, while a census tract level system has less than 1,000. The use of newer generation computers has only moderately improved the overall operation, as the major efforts are involved in both file generation and editing and computer software architecture. Frequently, urban information systems have become underutilized because of high manpower requirements for the initial encoding of data and the heavy expense involved in updating. Land use characteristics have consistently been the most expensive data to incorporate in information systems, primarily because there has been no subsidy available to the user in recording and preparing resource inventory data, such as occurs with demographic, economic, health, and assessor data sets.[5]

There are a number of ways to encode spatial data.[6] It is possible, however, for illustration purposes, to dichotomize referencing systems into nominal and ordinal, and data types into tabular, graphical, and image. Ordinal systems reference data by the actual geographical coordinate values. Thus, natural resources such as forests, rivers, crop land, and geologic formations are mapped with selected identifiers (total area, boundary, centroid) referenced to latitude and longitude or other selected geographic coordinate system. Nominal systems are "name referencing," i.e., data or information is referenced to a name-designating system. Any district-based referencing convention, such as census tract, sewer district, township, or transportation zone, assumes the operator knows where each administrative area is located and leaves the analysis of contiguity-effects, etc., up to the individual.[7] Problems invariably arise during the computational processing involved in conversions between ordinally and nominally referenced data and have, with the exception of the Census DIME (Dual Independent Map Encoding) File system, forced the conversion of all data to one reference system or the other.[8]

Of equal concern to the designer of a geographic information system is an incorporation of the various geocoded data types to assure adequate "data capture". It is only through the integration of tabular, graphical, and image data types that geographic information systems achieve the synergistic impact required to offset their initial cost. For instance, tabular files may keep records of individual weather stations, while graphical files record elevation contours, and image data sets the distribution of land use. The combination of all three data types would provide analysts with the variety of spatial data needed to model alternative sources of non-point source air pollution. The need to deliver a uniformly encoded result to the user has been a key element to changes that have occurred in both geocoding approaches and computer system architecture applied to geographic information systems.[9]

Approaches to Geocoding

There exist three principal geocoding architectures, which have evolved from simple grid cell systems to the complex polygon methodologies, and most recently include the image raster data type (see Fig. 1). From several recent reviews, it is

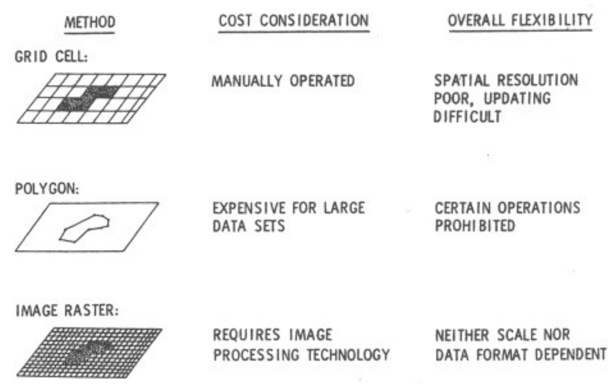

Figure 1. Approaches to Geocoding

evident that the goals of geographic information systems have become more ambitious as faster computer systems evolved and peripherals become more sophisticated.[10] Grid cell methods served the need to retrieve geo-located data and generate maps through the cross tabulation of variables encoded within a particular cell. Several important drawbacks reduce the overall flexibility of grid cell systems: (a) Their spatial resolution is only as accurate as the grid cell size (usually ranging from one acre to ten square miles); (b) The systems permit the referencing of data in either a nominal or ordinal manner, never both; (c) The need for manual encoding of the input data files has made updating difficult and even prohibitively expensive and effectively limited the spatial resolution of grid cells to satisfy the need to achieve regional coverage.

In response to the failings of grid cell geocoding, polygon systems grew as electronic coordinate digitizers became generally available. Polygon geocoding formats effectively solved the spatial resolution dilemma inherent with grid cell formats, while coordinate digitizing hardware has permitted rapid encoding of data. The most important achievement, however, was the integration of nominal and ordinal referencing in the Census DIME file methodology.[11] Despite these significant achievements, polygon geocoding systems have left the problem of ordinal data updating unresolved and created new challenges inherent in their graphical data structure. These problems include: (a) Considerable computational expense associated with file editing; (b) Complex topological architectures to achieve efficient data extraction from any given area;[12] and (c) Large investments in computer systems to achieve polygon overlay of separate files for encoding ordinal data into nominal encoding formats (e.g., acreage of land use for each census tract). Many of these constraints can be mitigated by the use of an image raster encoding procedure and application of digital image processing algorithms to implement geographic information system analyses.

Digital image processing techniques can be applied to interface existing geocoded data sets and information management systems with thematic maps and remotely sensed imagery. The basic premise is that geocoded data sets can be referenced to a raster scan that is equivalent to an ultra-fine mesh grid cell data set, and that images taken of thematic maps or from remote sensing platforms can be converted to a raster scan. A major advantage of the raster format is that x, y coordinates are implicitly recognized by their position in the scan, and z values can be treated as Boolean layers in a three-dimensional data space. Such a system should permit the rapid incorporation of data sets, rapid comparison of data sets, and adaptation to variable scales by resampling the raster scans.

Remotely Sensed Data Input

A major impetus to the creation of geographic information systems has been the desire to integrate land resource inventory data, derived from remote sensing imagery, with other geocoded statistics. The costs of acquiring and encoding remotely sensed data has frequently spelled the demise of an agency's plans to create a geographic information system, while the lack of funds for land resource inventory updates to match other statistical updates has frequently left systems in disuse.[13]

For several years NASA has sought to partially alleviate the financial burden of procuring remote sensing imagery useful to resource inventory assessment through the provision of high altitude and LANDSAT imagery at minimal cost to the user. The ability of IBIS to incorporate LANDSAT imagery directly in a geocoded system framework should help resolve much of the present impasse.

Monitoring Potential

The ultimate goal for NASA support to geographic information systems, periodic land resource inventory updates for statistical areas and semiannual maps locating areas that have undergone change, has yet to be achieved.[14] The technological limits of existing automated data processing systems and the resolution capability of the current LANDSATs have permitted only partially accurate classification and statistical results. Particularly in the urban scene, abrupt changes in land use occur over short distances and often several cover types occur within a particular class of land use. In a short distance, one may encounter asphalt freeways, residential areas with light colored roofs adjacent to those with dark colored roofs, and then concrete freeways.

The results of experiments completed to date show that the current generation of LANDSATs have a spatial resolution that can provide USGS Level II land use statistics of sufficient accuracy when aggregated at the census tract level or higher under closely edited test conditions.[15] Higher spatial resolution simulations of LANDSAT-C follow-on missions are proving that more thematic classes can be differentiated; and, more significantly, that more accurate acreage estimates by statistical analysis areas (e.g., census tracts) are to be expected.

Geometric Rectification

The ability to provide periodic updates from remotely sensed imagery implies that the analyst is able to directly superimpose data received at different dates. As Billingsley has recently pointed out, geometric rectification of digital image data sets to achieve image registration or conformance to specific map projections is not a trivial task.[16] Registration of sequential LANDSAT images has been demonstrated,[17] while a methodology for the superimposition of image and graphical data sets is described in the following section.

IBIS TECHNICAL DESCRIPTION

Because the image datatype is used, capabilities for digital image file handling, image manipulation, and image processing are required. Thus, the IBIS system has been built upon an existing image processing system, VICAR (Video Image Communication and Retrieval), developed at JPL.[18] Certain basic image processing operations are absolutely essential. One must accomplish image-to-image registration, whereby images of different scale, rotation, or map projection are superimposed precisely enough so that corresponding pixels represent the same geographic location. Rubber-sheet registration is almost always necessary to achieve the needed degree of accuracy. On the other hand, it is anticipated that even esoteric image processing operations, such as convolution smoothing will be useful for certain types of applications. The conclusion here is that any image-based information system must contain a powerful image processing subsystem.

Additional capabilities are then added to the image processing system to convert it into an image based information system. First, image data must be registered or indexed to spatially-referenced tabular data. For example, it may be desired to collate land use data contained in an image to census data contained in a tabular file aggregated by census tract. Conceptually, this can be likened to image-to-image registration, except that pixels are aligned with records, not with pixels. Second, a data interface must be provided between the different datatypes so that the results of processing can be stored. The next section of this report (Case 1) shows a case in which the processing of an image produces a tabular file which can be interfaced to other tabular files. Third, image processing analogs must be developed for existing geo-base file computational steps such as polygon overlay, aggregation, and crosstabulation. For example, the polygon overlay operation, in which areas of intersections of polygons from two data sets are obtained, is replaced by a two-image histogramming operation.

A user request is given to the IBIS system by means of a language which is translated into the host machine job control language. The translated code can then invoke system functions or processing modules. This organization makes the system flexible and easily extendable. The system software consists of a number of FORTRAN modules and a relatively small system nucleus. All of the factors mentioned here (modular design, use of FORTRAN, good interfaces to user and hardware) make technology transfer more feasible.

Case 1: St. Tammany Parish, Louisiana

St. Tammany Parish, near New Orleans, is divided into 13 transportation districts and subdivided into 44 transportation zones. For general purposes of engineering, planning, and management, it is desired to tabulate land use within each of these districts and zones.

Three pieces of input data are needed for this case: 1) a map showing the districts and zones, 2) a LANDSAT image of the same area, and 3) user-identified training sites which outline sample areas known to contain land cover types of interest to the user. A district outline map is shown in Fig. 2. Processing steps are shown in Fig. 3 with the input data at the top and desired output at the bottom. This case was simplified by redrawing the district map and training sites directly upon the LANDSAT image. The processing steps then were:

1. Digitize district map on a coordinate digitizer (manual, magnetic tape output).

2. Edit the polygon file to guarantee topological closure of regions (automated).

3. Extract the region of interest from a LANDSAT digital image and convert to a format suitable for classification algorithms (automated).

4. Digitize the training site map on a coordinate digitizer (manual, magnetic tape output).

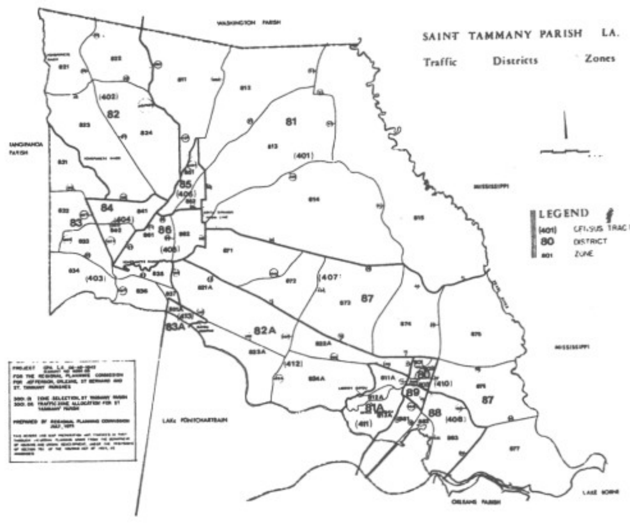

Figure 2. District Map

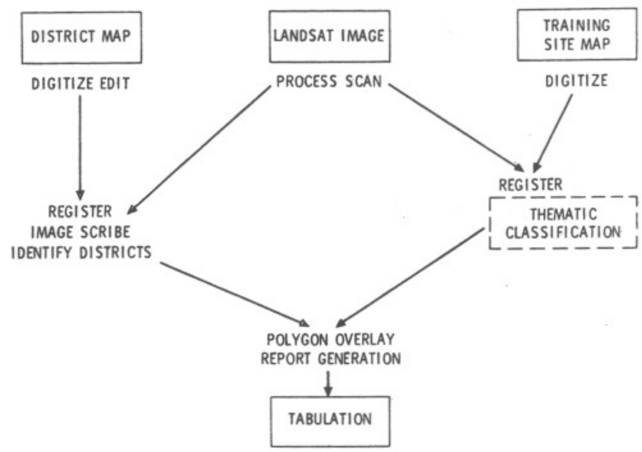

Figure 3. Processing Steps for Case 1

5. Convert the polygon district file into an image (automated).

6. Apply rubber-sheet stretching to achieve registration of districts to LANDSAT image as shown in Fig. 4 (automated, manual selection of tie-points.

7. Steps 5 and 6 repeated for training sites.

8. Apply mathematical classification[19] to the LANDSAT image and training sites to produce a thematic classification of the entire region of interest as shown in Fig. 5 (automated).

9. Identify the traffic zones in the administrative district image by painting each with a unique

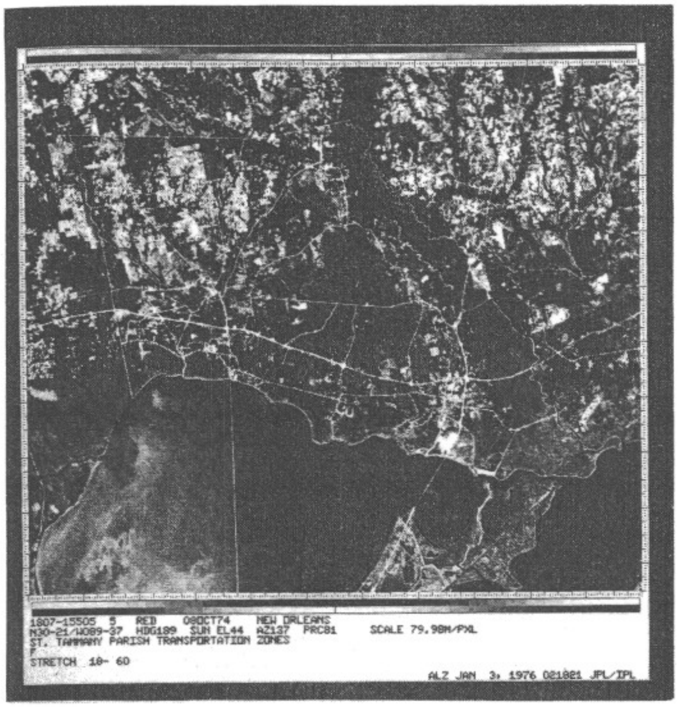

Figure 4. Overlay of District Boundaries and LANDSAT Image

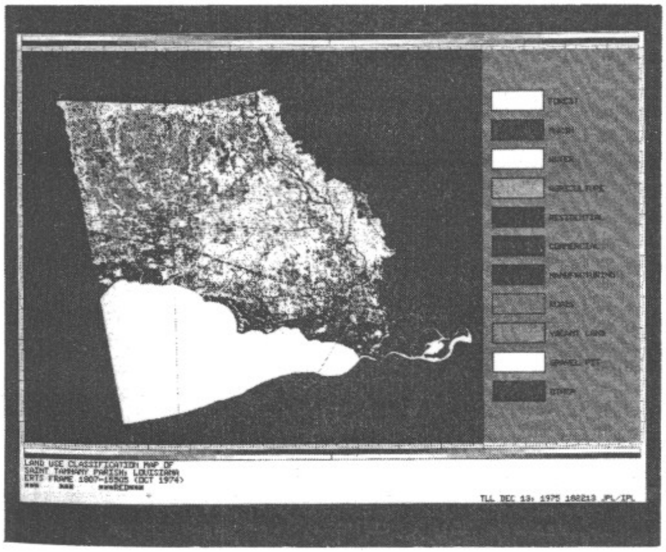

Figure 5. Thematic Classification Map

pixel value or grey scale as shown in Fig. 6 (automated).

10. Perform polygon overlay, summing the number of pixels of each thematic class for each of the colors painted in the administrative image. By overlaying the two images, each location corresponds to a pair of pixels, one representing a district and the other a thematic class. Polygon overlay then becomes a trivial histogramming operation on these pixel pairs.

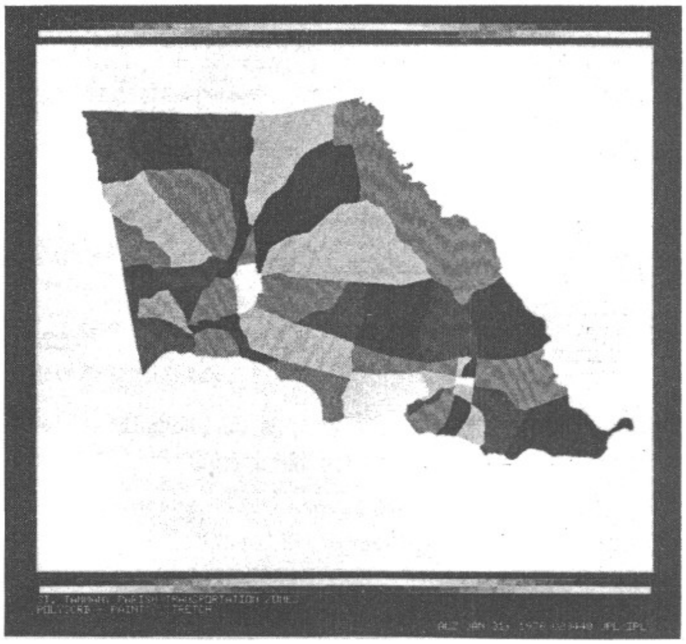

Figure 6. Transportation Zone Chloropleth Map

11. Convert the pixel histogram into a report with columns of land use by acres and percentages shown in Fig. 7. This involves a number of transformations in the data management and analysis portion of IBIS.

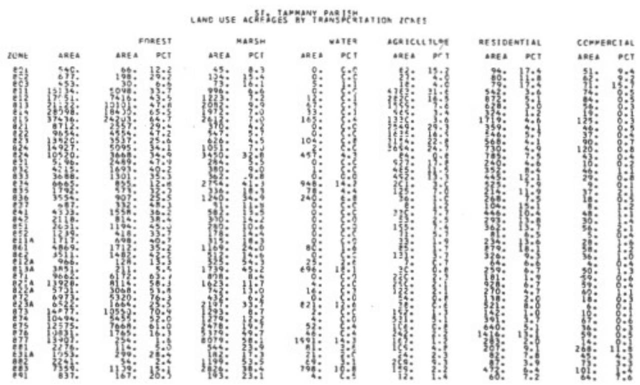

Figure 7. Land Use Tabulation

The theme class image is a useful product since it helps the user visualize the distribution of land use in his area of interest. But for purposes of analysis, the data must be aggregated according to the user's own districting. The IBIS system gives both products as well as other material (such as boundary overlays shown in Fig. 5). Fig. 8 gives a general view of the IBIS system from the viewpoint of data flow.

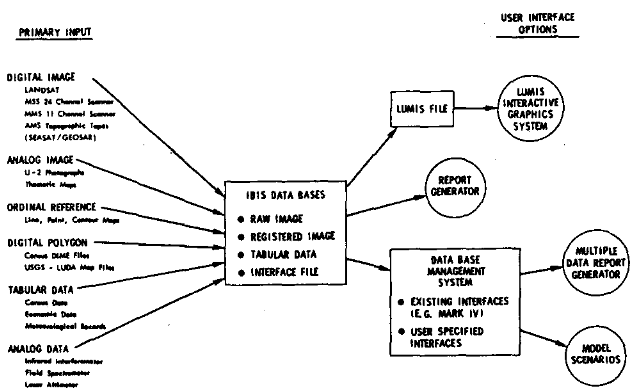

Figure 8. IBIS Data Flow

Case 2: Los Angeles County

A frequently used unit of aggregation in metropolitan areas is the census tract, defined by the U.S. Bureau of the Census. Census data are available by that unit and data gathered by other district conventions (e.g., fire district, police district) are often crosstabulated to census tract so that analysis can be performed. Moreover, annual statistical updates in metropolitan regions are made at the census tract level, but are not made for a smaller unit of aggregation. In this IBIS application, it is desired to tabulate land use by census tract. Los Angeles is a large case involving thousands of square miles and over 1500 tracts. The tracts have been coordinate digitized and edited by the Census Bureau and are available at low cost on magnetic tape.

Referring back to the processing steps for Case 1, the first two steps are eliminated. In their place, a tape handling routine converts the census tape contents to IBIS polygon file format, then a polygon rotation routine converts the longitude-latitude coordinates to line-sample coordinates in approximate registration to the LANDSAT image. Rubber-sheet registration using about thirty tie points then obtains precise registration.

Except for the steps leading to thematic classification, the Los Angeles case is less costly than the St. Tammany Parish case and demonstrates the economies of scale inherent in the IBIS system.

Future Application

Along with the real world cases just discussed, IBIS has been tested on several hypothetical cases: 1) City analyst wants to convert tabular data which has been aggregated by various districts (police, fire, etc.) to data aggregated by census tract. 2) Sewage utility planner wants to know the amount of non-porous surface area for each storm sewer district. 3) Natural gas utility planner wants to know the surface area of roof per capita for each power substation service area to predict potential impact of solar energy systems.

The above cases have been implemented on a test basis and can easily be upgraded to application status. The first and third cases are particularly interesting because they interface image data to tabular data. The third case best illustrates the power and flexibility of IBIS. Assume that surface area of roof is obtained in image form where pixel value represents the amount of roof (perhaps by a transformation upon thematic classes). If a power district image is created, then roof area can be aggregated by those districts. Population figures are available by census tract, so a census tract image is created and population data is crosstabulated to power district. A division of tabular columns obtains the roof area per capita figure.

Future applications are anticipated in the area of spatially-referenced modelling, especially where the image datatype and image processing operations can be a powerful component of the model.

CONCLUSIONS

An image-based information system is necessary for the full utilization of satellite imagery data and anticipated development of regional land capability analysis centers.[20] The future availability of frequent updates of land resource inventory statistics, with a known and acceptable sampling accuracy, should permit the incorporation of this data with the annual updates published by other governmental bureaus. An image based information system does more than introduce remotely sensed imagery to the mainstream of data processing application; it provides a new approach to the management and analysis of spatially-referenced data.

The projected demands to be placed upon geographic information systems will place a strong emphasis upon the capability to store and retrieve large amounts of data and manipulate data sets for portions of the files efficiently. A major drawback facing most geocoding procedures is that they rely on sequential computations applied to tabular data strings, and as such require a large investment in formatting or processing data that is inherently two-dimensional. Raster scan data bases will avoid many of these problems and possess additional advantages. The video communications field has been and is continuing to address both the problems of mass storage and applications of rapid interactive processing that places a minimal reliance upon computer software routines. The specialized requirements of geographic information systems should derive considerable benefit from the image processing field in the future.

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