REMOTE SENSING FOR URBAN PLANNING

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ABSTRACT

Utility companies are challenged to provide services to a highly dynamic customer base. With factory closures and shifts in employment becoming a routine occurrence, the utility industry must develop new techniques to maintain records and plan for expected growth. BellSouth Telecommunications, the largest of the Bell telephone companies, currently serves over 13 million residences and 2 million commercial customers. Tracking the movement of customers and scheduling the delivery of service are major tasks for BellSouth that require intensive manpower and sophisticated information management techniques. Through NASA's Commercial Remote Sensing Program Office, BellSouth is investigating the utility of remote sensing and geographic information system techniques to forecast residential development. This paper highlights the initial results of this project, which indicate a high correlation between the U.S. Bureau of Census block group statistics and statistics derived from remote sensing data.

INTRODUCTION

Utility companies, faced with increasing state and federal regulations and a growing customer base, are turning to spatial technologies to maintain records and predict future facilities expansion. The average household moves every 4.5 years, placing heavy demands on antiquated mapping and database techniques for tracking this dynamic customer base. Geographic information system (GIS) technology is becoming common throughout the utility industry as a tool to manage company resources and ensure service to its customers. Nowhere is this need more critical than with the telecommunications industry. As the primary source of communications for customer access to everything from business operations to emergency response, accurate information concerning customer requirements is critical to providing stable service. Furthermore, knowledge of changing patterns of customer location enables telephone companies to plan facility improvements so resources are in place to serve a growing population.

Nowhere is the challenge of tracking a growing customer base and planning for new service in the telephone industry more demanding than at BellSouth Telecommunications, which serves the southeastern United States. Population shifts over the past few years have resulted in dramatic increases in such metropolitan areas as Atlanta, GA and Orlando and Miami, FL, with significant increases in other areas as well. BellSouth Telecommunications currently serves over 13 million residences and 2 million business customers within a 200,000-square-mile territory in 9 southeastern states.

BellSouth maintains an extensive database on its customers and service area. However, this database lacks sophisticated information on the location of services and the spatial relationships between customers and service areas. BellSouth recognized the opportunity for using GIS and remote sensing to improve their proprietary database and in 1990 entered into a cooperative partnership project with NASA's John C. Stennis Space Center and the University of South Carolina (USC) under NASA's Earth Observations Commercial Applications Program (EOCAP). This project is a 3-year effort to develop and integrate an improved model for market forecasting. This paper will discuss a portion of the BellSouth/NASA/USC project dealing with residential land use model development and the use of remote sensing to enhance the model.

RESIDENTIAL HOUSING INVENTORY USING REMOTELY SENSED DATA

The wire center is a basic unit of geography representing the smallest division of phone service offered by the telephone utility. A wire center's geographic extent is determined by the range of cables and wires in an area served by a common three-digit telephone number prefix. Information gathered at the wire service level is aggregated to higher levels for overall analysis.

BellSouth Telecommunications needs to know the location of each single-family home, multi-family residence (duplex, triplex), apartment complex, and trailer in each wire center. These data cannot be obtained using Landsat 30 x 30 m Thematic Mapper, SPOT HRV 20 x 20 m multispectral, or even SPOT 10 x 10 m panchromatic data.[1,2] Therefore, emphasis for this study was placed on demonstrating how BellSouth will be able to use remotely sensed image data becoming available in the later part of this decade (e.g., proposed SPOT 5 and Landsat 7 will have 5 x 5 m spatial resolution). The BellSouth model had to be developed using commercially available data so as not to base company-critical information on an unreliable source. In order to acquire data to function as a surrogate for future high spatial resolution, satellite-derived remote sensor data, NASA's Calibrated Airborne Multispectral Scanner (CAMS) was flown over the Dutch Fork Wire Center in Columbia, SC to obtain data at 5 x 5 m spatial resolution. The CAMS data were rectified to a UTM projection using high 3rd-order polynomial equations.

Various transformations of the nine channels of CAMS data were used to extract individual dwelling units from the imagery.[3] The dwelling units were obtained by ratioing the data, thresholding to identify house pixels, grouping like pixels or "clumping" the house pixels, and converting the raster clumps into polygons with their own area and perimeter.

The absence (or presence) of dwelling units extracted from the 5 x 5 m CAMS data was compared with the number of units summarized in the block group statistics of the 1990 U.S. Census of Population. The results were remarkably consistent with an r^2 of .97 (Pearson product moment correlation, r = .987). Satellite remote sensor data having $\leq$ 5 x 5 m spatial resolution will provide valuable housing stock information for BellSouth Telecommunications when it becomes available.

Digital National Aerial Photography Program (NAPP) data are also being investigated as a possible source of housing count information.[4] However, it is unlikely that NAPP 1:40,000 scale aerial photography obtained approximately every 5 years will meet BellSouth's yearly requirements, and currently available commercial systems do not provide sufficiently high spatial resolution imagery.

In addition to documenting existing residential dwellings, it was also important to predict where future residential development might occur. Two approaches were investigated to predict such development. First, an

empirical method was tested using selected land use planning variables and Boolean logic. Second, two predictive models based on the use of 1980 and 1990 U.S. Census of Population data, building permits, and county land use information were used to develop analytical models of future growth.

An Empirical Model of Residential Development

The following spatial variables for a portion of the Dutch Fork Wire Center were placed in a raster GIS:

- 100-Year Flood Plain Map of Lexington County
- 1992 Lexington County Land Use Zoning Map file
- 1992 Lexington County Land Use Zoning file updated using remote sensing
- Lot size computed using remote sensing data ($<$ ¼ ac; ¼ to ½ ac; $\geq$ ½ ac)
- CAMS 5 x 5 m multispectral data (for planimetric detail)

These data were then queried using Boolean logic to identify areas which have a high probability of becoming residential at specific housing densities. It is instructive to review how the variables were created and analyzed.

Few developers in South Carolina build residences in areas below the 100-year flood plain contour; therefore, these areas do not have a high probability of residential development and can be effectively removed from further analysis. County land use zoning maps are very important sources of future development information. The zoning file identifies residential development, commercial development, and those areas not yet developed. This type of information is dynamic and rapidly becomes outdated. For example, a Lexington County Zoning Map obtained for this study did not identify two major residential subdivisions already in existence. These subdivisions are easily identified on the CRT screen, and "heads-up" digitizing may be performed to update the land use zoning file.

Photogrammetrically derived length and width measurements of the residential subdivisions in conjunction with housing information (previously discussed) can be used to compute a housing density statistic per residential area. Land tracts within the wire center, which were not within the floodplain and were zoned "ready for development," were assigned to the closest housing density category in geometric space. Finally, the actual land available for residential development and its predicted density were depicted. The area of each potential tract can be computed and used to determine the average number of homes which can be located in a tract. Such predictive information is very important to BellSouth and can be obtained using relatively straightforward remote sensing and GIS technology.

An Analytical Model of Residential Development

The decennial national census provides a wealth of residential information. Typically, the longer the time from the last census, the greater the amount of error in population estimates. The fundamental need is to generate accurate inter-census inventories of urban development and to estimate where new development will occur. In order to meet these needs, an analytical study is underway to develop an integrated GIS and remote sensing environment that can be used to monitor urban expansion between census periods over large geographic areas. It addresses the need to capture systematically and analyze a wide range of data sources that are *surrogates* of urban development. A study area centered on the Columbia, SC Metropolitan Statistical Area (MSA) consisting of Lexington and Richland counties was used to test the methodology. Although the MSA contains 20 incorporated cities, 85% of the land within these counties is undeveloped.

The most important indicator of residential development is the change in the number of housing units. These data are tabulated by the Bureau of the Census every ten years. Therefore, it is possible to use the change in number of houses between 1980 and 1990 as a benchmark for examining other indicators of urban change. The 1980 and 1990 census tract polygons were chosen as the unit of measure because the two dates had similar boundaries and geographic extent. Once a geographic correspondence in tract polygons and tract

number was established, the 1990 housing counts were linked to the 1980 tract polygons. The total population change from 1980 to 1990 in Richland and Lexington Counties was +40,221 and the total housing change was +34,017. Twenty-four census tracts lost housing between 1980 and 1990, mainly in the downtown area of Columbia. The areas with the greatest increase in housing units were located in the suburbs in northeast, northwest, and west Columbia. The goal of the research was to compare surrogate measures of urban change that could be used to estimate the rate of change in number of houses and the spatial distribution of these changes. The first surrogate was based on the use of remotely sensed data.

Forecasting Residential Land Use Change Using Satellite Remote Sensor Data

Because no 1980 land cover information derived from satellite data existed, 1976 U.S. Geological Survey land use and land cover data derived from 1:60,000 aerial photography were used as the initial baseline. These data represent an inexpensive source of land cover data available for the entire United States.[5] The polygonal land cover data are summarized in seven Level II classes.

Previous research has shown that SPOT imagery can be used in detecting urban fringe growth.[6,7,1] A 1990 SPOT image was analyzed using traditional unsupervised classification techniques to identify the same seven land cover classes.[8] The algorithm used to convert the 1990 raster data to polygonal data was an edge-stepping algorithm.[9,10] To determine the amount of change from 1976 to 1990, the two classifications were intersected to create a composite land cover change file.[11] The composite layer was intersected with the 1980 census tract polygons to determine the land cover change by tract. The amount of change from rural to urban was obtained by performing a polygon overlay analysis. This operation identified all polygons which were undeveloped land in 1976 and developed land in 1990. These data were moderately correlated with housing change at the Census tract level (r = 0.68). The predictive model

$$\%\text{Change in Housing} = .005 + .538 \, (\%\text{Change in developed land})$$

provides a useful initial analytical model for forecasting future housing. Using this model, it is possible to estimate housing by monitoring land cover changes from remote sensing sources.

Forecasting Change Using Building Permit Applications

Another analytical approach to monitoring urban change was based on building permit transactions. The Central Midlands Regional Planning Council maintains a tabular database of all building permits issued by Richland and Lexington County, including number, street, city, county, month, year, school district, demolition, tract number, cost, type of construction, number of units, subdivision name, tax map number, and number of permits. To convert the building permit data into a GIS database, it was necessary to locate each permit geographically and link the attributes to the location. This geocoding process utilized a new BellSouth proprietary address-matching tool.

Between 1981 to 1990, 15,975 building permits were issued in the study area. Using the proprietary geocoding methodology, 67% of these permits were successfully address matched. These points were then aggregated at the census tract level and compared with the estimated housing change over the past decade. From these data, a regression procedure was used to generate a predictive analytical model for the period from 1980 to 1990:

$$\%\text{Change in Housing} = .002 + .883 \, (\text{change in building permits}).$$

A high correlation (r = 0.84) suggests that tracking building permit data provides a good way to monitor housing changes. The EOCAP II project research is now focusing on the relationship between the satellite-based residential change detection and the building permit activities.

CONCLUSION: DATA INTEGRATION

The benefits of these approaches to monitoring and modeling urban changes are evident when the various types of data are integrated into a GIS data base. While the census provides indispensable data for urban forecasting, of necessity it is aggregated both spatially and temporally. Both the remotely sensed data and the building permit information can be examined on a continuous basis at a much finer level of spatial detail than census areas. The power of this type of data integration is readily apparent when individual neighborhoods are examined. Point level data (building permits, commercial firms, and retail center locations), linear features (highways, water lines, and sewer lines), various areal features (including census polygons), and change in urban land use may be integrated. The EOCAP project is now concentrating on the creation of a robust housing model that incorporates these data sources into an improved wire center forecast.

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REMOTE SENSING AND THE MISSISSIPPI
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ABSTRACT

Since 1986, the National Aeronautics and Space Administration's (NASA) Commercial Remote Sensing Program (CRSP) at Stennis Space Center has supported commercial remote sensing partnerships with industry. CRSP's mission is to maximize U.S. market exploitation of remote sensing and related space-based technologies and to develop advanced technical solutions for spatial information requirements. Observation, geolocation, and communications technologies are converging and their integration is critical to realizing the economic potential for spatial informational needs. Global Positioning System (GPS) technology enables a virtual revolution in geo-positionally accurate remote sensing of the earth. A majority of states are creating GPS-based reference networks, or High Accuracy Reference Networks (HARN). A HARN can be densified for a variety of local applications and tied to aerial or satellite observations to provide an important contribution to geographic information systems (GIS). This paper details CRSP's experience in the following areas: (1) design and implementation of a HARN in Mississippi, and (2) design and support of future applications of integrated earth observations, geolocation, and communications technology.

INTRODUCTION

The NASA CRSP at Stennis Space Center supports the spatial information industry through a data acquisition and processing infrastructure. In conjunction with its partnerships with companies and the private sector, the CRSP acquires and processes aerial and satellite imagery for use in the development of geographic information systems. These data are georeferenced, a process by which the geometry of image areas are made planimetric, and entered into a data base, where the layers of data are tied to local reference grid systems. Often the control-point intersections of several data layers do not overlay precisely (Figure 1) because the data are derived from a variety of sources. This occurrence is referred to as the misregistration of data layers. In 1991, in an effort to correct the misregistration problems encountered at Stennis, the CRSP decided to densify the local reference network around the site and its neighboring region using technology provided by the Global Positioning System.[1,2] At this time the CRSP became aware of the National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey's (NGS) endeavor to implement the HARN on a
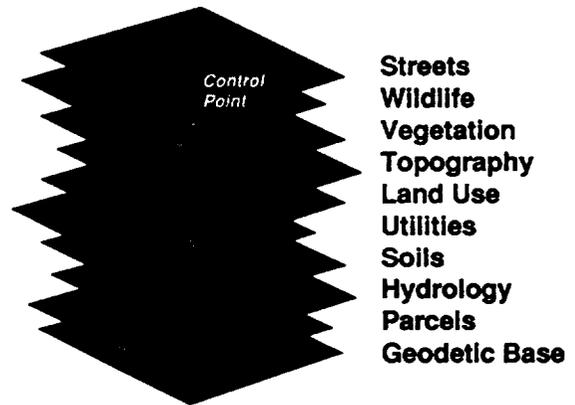

Figure 1. Misregistered Data Layers