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DETECTING AGRICULTURAL TO URBAN LAND USE CHANGE FROM MULTI-TEMPORAL MSS DIGITAL DATA*

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ABSTRACT

Conversion of agricultural land to a variety of urban uses is a major problem along the Wasatch Front, Utah. Loss of agricultural production is one problem; another is the changing water consumption patterns that result from the land use conversion. Although Landsat MSS data is a relatively coarse tool for discriminating categories of change in urban-size plots, its availability sometimes to the exclusion of other diagnostic data prompts a thorough test of its power to detect change.

This paper presents the procedures being applied to a test area in Salt Lake County, Utah, where the land conversion problem is acute. Results will be presented during the conference session. The objectives are to determine not only change but the identity of uses before and after conversion and to compare digital procedures for doing so. Class selections are predicated on water consumption categories. The question is, how well can MSS data be made to identify these class types, and at what minimum plot size? Several algorithms are being compared, utilizing both raw data and preprocessed data. Verification of results involves high quality color infrared (CIR) photography and field observation. Selection of Landsat dates was determined by available CIR data, in this case involving a two-year time span, from 1979 to 1981. The two data sets have been digitally registered, specific change categories are being internally identified in the software, results tabulated by computer and "change maps" are to be printed at 1:24,000 scale. This digital analysis should help develop an automated procedure for wider area application and for subsequent updating without the necessity of repeated CIR photography.

INTRODUCTION

Salt Lake County, which represents Utah's major population center, continues to experience rapid urban growth. The impacts of urbanization on land use patterns and natural resources in the county are of particular interest to both state and local policy makers. The effects of urban development on a dwindling agricultural land base and water

resources must be assessed to allow a rational basis for policy formulation.

There is a need to have the capability to monitor land use changes on an annual basis. Since it is impractical to expect that aerial photography may be obtained at such frequency, the logical choice is Landsat to provide repeated remote sensing data. Landsat data offers the additional advantage of being in digital form, thus obviating the need to perform the laborious process of repeated preparing and digitizing of line maps.

The objective of this study may be stated as follows: to utilize color infrared (CIR) photography and maps to calibrate a digital land use map from Landsat data, for the purpose of establishing a data base which may be updated in future years without the necessity of having repeated aerial photography coverage. Since this research project was underway at the time this paper was prepared, most of the results will be presented at the fall A.S.P. Conference. This paper focuses on the methods which have been and are being applied to accomplish the objectives noted above.

STRATEGY

The basic strategy is to establish 1979 as the base-line year, from which all subsequent change would be calibrated. For the baseline year, the most effective and accurate digital classification would be developed for the land cover types and sizes involved. The spatial/spectral data would remain on file for all future date comparisons. Updating might then be accomplished with simpler change detection algorithms.

The procedure for this research is to (a) experiment with a variety of classification algorithms and select the combination yielding the best results, using this to map the 1979 baseline stage, and (b) to experiment with various change detection algorithms to determine the most effective update procedure.

METHODS

The first step was to identify a representative test area within the county. A test block approximately 15 by 15 miles was found to contain all the major urban and agricultural types of interest. High quality CIR photo-graphy (1:30,000 scale), within one month of the Landsat digital data set, is being used to assist in identifying and calibrating cover features for that base year.

The digital procedures described below are being used to detect changes occurring between the base year (1979) and 1981. CIR photography (1:60,000 scale), within one month of the Landsat data set, is being used in the analysis of the 1981 Landsat data.

The analysis and mapping performed in this study are being carried out at the facilities of the Center for Remote Sensing and Cartography, using digital data

obtained through NASA's Landsat satellite system from the
EROS Data Center. For data processing, the Center is
utilizing the "ELAS" package of computer software routines,
developed by NASA's Earth Resources Laboratory, which is
operational on the University of Utah Research Institute's
PRIME computer.

The primary rationale for performing digital process-
ing of MSS data begins with the assumption that different
types of ground cover have different patterns of reflection.
It is also assumed that these spectral patterns are
sufficiently unique to make different ground cover types
consistently distinguishable from one another using
statistical classification techniques (Hutchinson 1982).

Standard Digital Data Analysis

Ground cover characteristics may be analyzed using
digital image data from a variety of sources: Landsat
multispectral scanner (MSS); Landsat thematic mapper (TM);
airborne thematic mapper simulator (TMS); NOAA satellite
sensor, advanced very high resolution radiometer (AVHRR);
etc. The description of methods in this section applies to
the analysis of digital image data from any such source.

Any digital image data must first be reformatted to
make them compatible with processing hardware. Next, a
grey level map is produced which encompasses the study area
and some of the surrounding area. The size of the grey
level map is determined by the number of features present
to be used as ground control. As water bodies typically
provide the sharpest and most spectrally distinctive
features for control, a near infrared band is generally
used to produce the map. (See Stage 1 of Figure 1.) These
ground control points are used later to geographically
reference the digital data to remove the effects of earth
curvature, spin, etc. (See Stage 3 of Figure 1.) At this
point of data processing, the raw data may be modified by
other analytical steps such as filtering, principal compon-
ents analysis, etc. Thereafter, a program called "SEARCH"
is utilized to generate statistics which characterize
pixel groups having similar spectral features across the
bands. (See Stage 2 of Figure 1.) SEARCH is a routine
which is used to provide training statistics for a program
called "MAXL," which classifies individual pixels into a
class based upon each pixel's highest statistical probabil-
ity of belonging to a given class. The training statistics
are derived from blocks or windows of data which correspond
to areas on the ground containing the cover types of
interest.

Once the study windows are selected, the SEARCH program
examines each contiguous six scan line (Landsat pixel
matrix "row") by six element (pixel matrix "column") block;
if the spectral data within the six by six block are too
heterogeneous, the program will switch to the use of a three
by three block of pixels. The statistics generated by
SEARCH include mean pixel light reflectance values for each
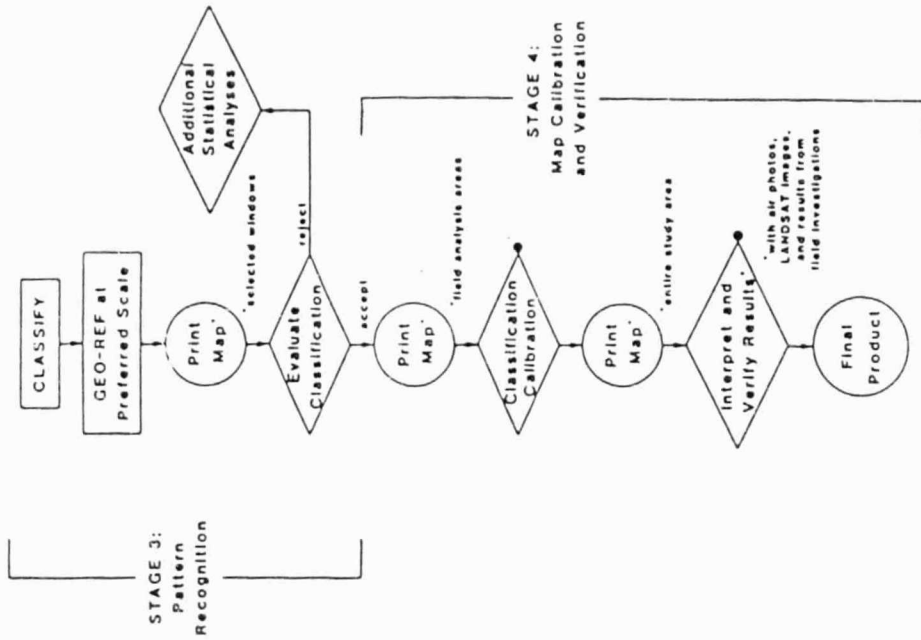of the four bands, a covariance matrix, and a priori values.
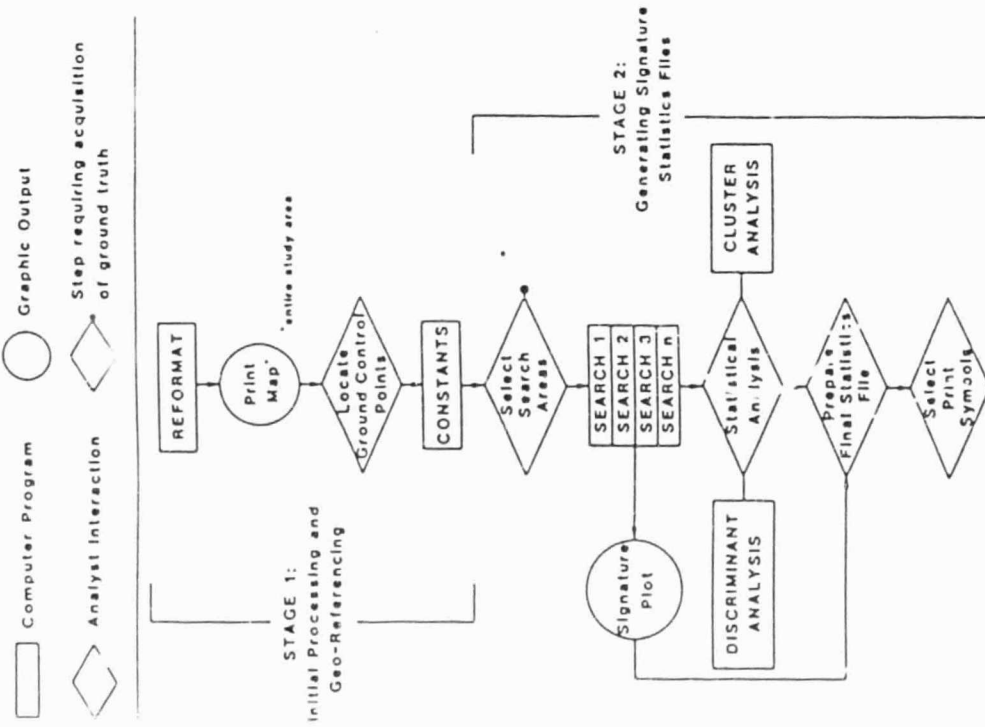
Figure 1. Summary of CRSC steps in Landsat digital data analysis.

A set of statistics is generated by SEARCH representing various classes of light reflectance patterns found in the study area "searched." The mean light reflectance values for each spectral band are plotted to form a signature which characterizes each class. SEARCH thus "trains" MAXL to recognize different ground cover patterns as it places individual pixels into classes. A knowledge of the manner in which different land cover features create spectral signatures, combined with the analysis of aerial photography and field checking of digital classifications, allow the researcher to provide an interpretation of Landsat-derived spectral classes, characterizing the various signatures according to ground information.

After light signatures are produced, further efforts are directed toward finding those signatures which would most likely reflect the major land cover types of interest. Stage 2 of Figure 1 illustrates several of the steps utilized in making detailed studies of signatures. A signature plot permits a substantial amount of interpretation; spectral signature shape and magnitude of reflectance are diagnostic of land cover types. Generally, similarly shaped signature curves indicate similar cover types while upward or downward shifts of similar curves indicate differences in topography, amount of ground cover, or the amount of mixing with other cover types, changing the overall "brightness."

At CRSC, there has evolved a somewhat "standard" set of statistical routines to deal with an often unmanageable number of spectral classes. The sequence involves principal components analysis, cluster analysis, and discriminant analysis, leading to a final classification. This sequence of routines may be applied to raw data or modified raw data (e.g., filtered, enhanced, etc.). The remainder of this section describes the application of these routines to Landsat MSS data, as performed for the Salt Lake County study area data. The analysis of signatures from other digital image data would be similar.

Spectral signatures are then studied statistically to detect similarities and differences, which are not always distinguishable from the signature plot. First, a principal components analysis is of the mean values for each signature's four MSS bands reduces such data to factor scores for two components; typically bands 4 and 5 are combined into one component (visible light), and bands 6 and 7 combine to form the second (infrared light). Next, the factor scores are used in a cluster analysis which groups spectral signatures according to a similarity index. Finally, the factor scores and group clusters are used in a discriminant analysis of the signatures. A two-dimensional scatter plot produced in the discriminant analysis allows one to obtain a graphical view of the spectral context in which a particular signature is found. (See Figure 2.) The discriminant analysis scatter plot, with the two axes representing visible and infrared light components, may be divided into regions or groups of signatures that correspond to similar ground cover types. This process is a vital link in allowing an often
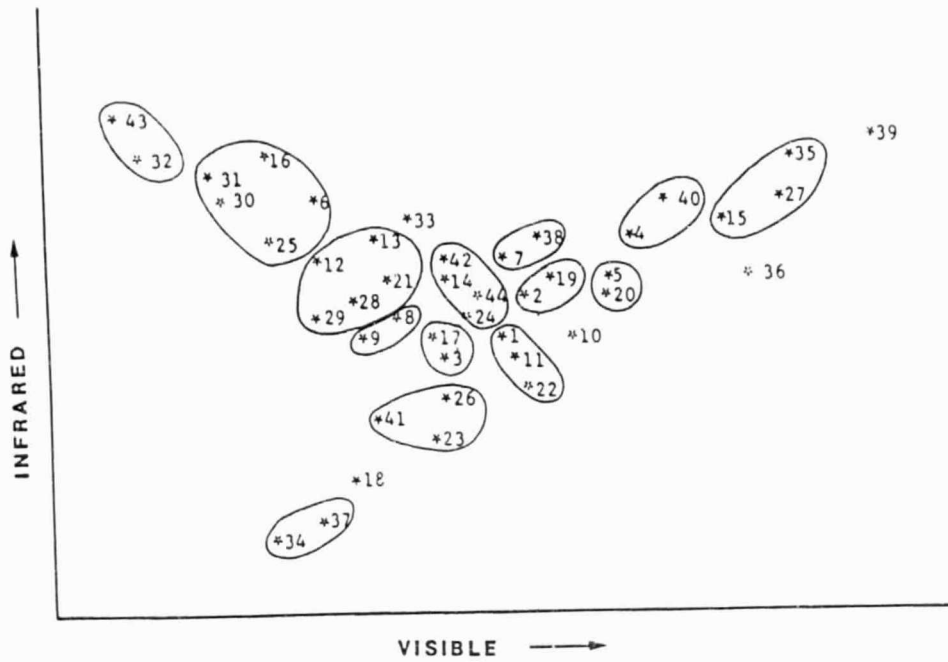
Figure 2. Scatter plot generated from discriminant analysis
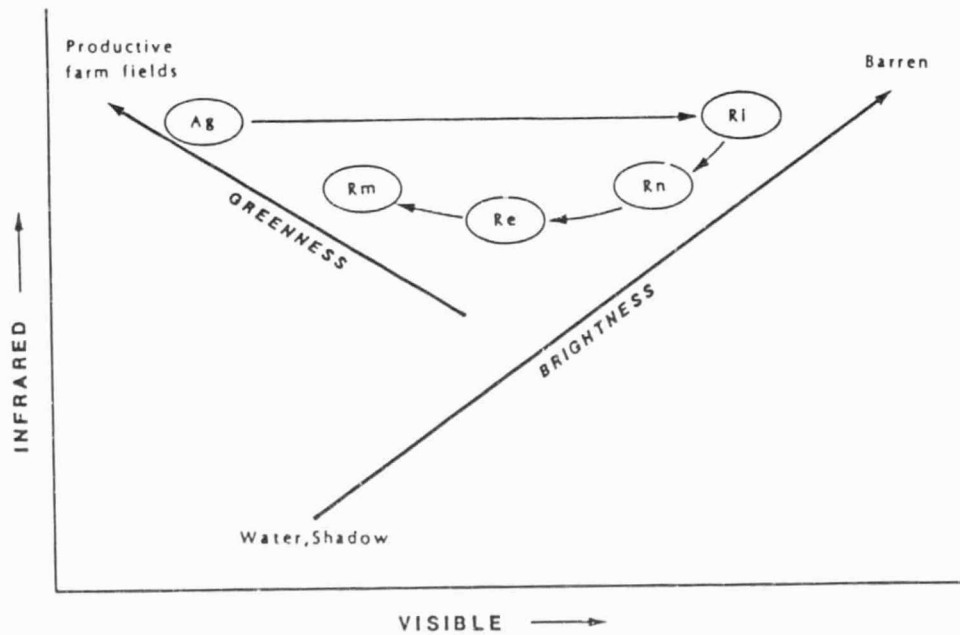of filtered Landsat data in the Salt Lake County
test area.

Figure 3. A theoretical model of agriculture-to-urban land
use conversion.

unmanageable number of signatures to be combined into groups of similar signatures. This procedure allows the researcher a great deal of flexibility in performing Landsat digital analysis; a large number of signatures are available and one may concentrate on the signatures of particular interest, while signatures of lesser interest may be grouped together or omitted.

A vital dimension to the process of digital data analysis is calibrating spectral signatures with ground information. By assigning a print symbol to each signature or signature group, a print map may be prepared and registered to standard base maps (e.g., U.S.G.S. 7½ minute quadrangles) and referrenced to photographs and field study sites. In this way, signatures are calibrated with actual land cover types. The use of discriminant analysis, based on MSS principal components and cluster analyses, in combination with examination of spectral signature plots and field experience (as outlined in Stages 2, 3, and 4 of Figure 1), has been a key element in achieving good results from the unsupervised approach to Landsat data analysis (e.g., Merola, et al. 1983; Ridd, et al. 1983).

Modified Raw MSS Data Analyses

The procedures described above have been applied to both raw and modified Landsat data.

Filtered Data. Reformatted Landsat data were spatially "filtered" to increase homogeneity of pixel spectral values within a given cover type. The filter routine uses an unweighted moving average, or low pass filter. (See Jensen and Toll 1982.) In general, data filtering involves adjusting raw spectral values for a given pixel to reflect the average spectral reflectance of a three by three pixel matrix around that pixel. This process tends to smooth out subtle spectral differences within an area which often results in the enhancement of edges between areas that have significant spectral differences (Haralick 1979).

Principal Components. As part of the ELAS program package, there is a program which derives principal components from raw data. The program then outputs, on a pixel-by-pixel basis, the component score for the pixel based on the principal component being used. This program does not rotate the components. If it did rotate the components, one would be able to derive two componer : in a single analysis, one for the two visible bands and one for the two infrared bands; the two components would then be orthogonal or uncorrelated to one another (Johnston 1978). Since this is not currently possible, we derived our components in two separate analyses, one to derive the visible component and one to derive the infrared component (Walker and Shu 1982). Although these components are not orthogonal to one another, they are very close to being so, and should provide information about the use of this technique.

Thematic Mapper Simulator Data Analysis

The thematic mapper simulator (TMS) is a multispectral scanner flown from an aircraft to simulate the TM data that will be available from Landsat 4. The goal in this analysis is to compare MSS data from earlier Landsat satellites and TMS data to identify the possible role of TM and its use in the future.

It has been stated by several authors that an improved spatial and spectral sensor, such as the TMS sensor, does not necessarily improve classification accuracies when processed the same as MSS data. The problem, as stated by Wharton (1982), is as follows: "To illustrate the problem, consider the task of distinguishing between commercial and residential land-use classes in [spatially] high-resolution remotely sensed data. A straightforward per-pixel spectral classification of the data can identify only the spectrally dissimilar ground cover classes such as pavement, lawn, trees, roof. These components are common to both the commercial and residential land-use classes, making it difficult to distinguish between them on a per-pixel basis. It has been suggested by several authors that the solution to this problem is the use of contextual information (i.e., the local frequency distribution of components surrounding each pixel." A contextual reclassifier is being developed, at this writing, to address this problem. Spatial and spectral contextual information are applied in the procedure. The spectral contextual information is supplied by the statistical analysis of the signatures, as described previously. The two-dimensional scatter plot produced in the discriminant analysis is based on discriminant scores produced in the analysis. These discriminant scores supply the spectral contextual information. The spatial information is supplied by a moving window, of specified dimensions, and a similarity matrix, derived from the discriminant scores, to evaluate the center pixel of the moving window. The center pixel is then reclassified if the specified parameters are met. This procedure will be tested on MSS as well as TMS data.

Change Detection Data Analysis: Image Differencing

Image differencing involves subtracting the digital values of one image date from another, on a pixel-by-pixel basis. The first step in image differencing is to register each image to UTM coordinates using ground control points. The results of the differencing are transformed into positive values by adding a constant, and a histogram is produced from the differenced image. As Jensen and Toll (1982) have stated: "A critical element of the image differencing method is deciding where to place the threshold boundaries between change and no change pixels displayed in the histogram." Jensen and Toll found that image differencing with band 5 produced the best definition of agricultural-to-urban change for fall data in the Denver area. The present study has, tentatively, shown greater promise using band 7 data from mid-summer.

Other differencing routines are being examined as well. A band 7/band 5 ratio was performed to combine the attributes of those two bands to detect change. Another technique being evaluated is a ratio of principal components. The ratio of visible/infrared was done on the two dates separately, then the two dates were differenced to form a differenced image. Another differencing technique utilizes a Multi-Temporal Vegetation Index (MTVI), presented by Derenyi, et al. (1982). A Vegetation Index (VI) was computed for each date as follows:

$$VI = \frac{band\ 7 - band\ 5}{band\ 7 + band\ 5} \cdot K$$

then, the VI for one date is differenced from the other:

$$MTVI = VI(T2) - VI(T1)$$

Each of these techniques has shown some promise in various parts of the study area. Some are more effective for conversion of dry farm, others for rangeland, and others for irrigated land.

Postclassification Improvement

Following spectral classification, selected ancillary terrain features are digitized to stratify cover types otherwise confused by spectral analysis. In addition, certain masks are created for "fixed" cover types, such as parks, golf courses, and public spaces that are spectrally confused with desired classes. These stratified and masked data files remain in the operating system for use in subsequent date change detection.

Verification

The accuracies of the several methods being explored are assessed using 247 ground verification plots. These plots have been digitized and can be compared to any map produces. The comparison is performed by a program in ELAS (ACTB) Accuracy of Classification Table. The table which is produced is an error matrix that shows class frequencies, percentages, percent correct, omission errors, and comission errors as a result of the comparison between the verification data and the classified data.

A Model of Land Use Conversion

The scatter plot in Figure 2 shows the 44 signatures derived from filtered data in the Salt Lake County test area. Signature groupings have been determined by analysis of the scatter plot, coupled with a signature plot from SEARCH, a classified print map, and field and photo observation. Each group is associated with a particular land cover type, relevant to the land conversion process.

Figure 3 presents a graphic illustration of a theoretical model of agriculture-to-urban land conversion in Salt Lake County. Irrigated farm lands occupy the upper left

region of the scatter plot. From this point, a field cleared for urban use dramatically shifts to the upper right region of the plot. Incipient residential (Ri) initially responds as barren land. New residential areas (Rn) have had some homes and streets constructed, which reduces brightness but have little effect on greenness. Initial landscaping established residential (Re) areas, and eventual maturing of residential vegetation (Rm) draw spectral characteristics toward the agriculture region of the plot.

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