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Detecting Residential Land-Use Development at the Urban Fringe

Band 5 Landsat spectral data and derived texture data provided complementary information, and when used together increased change detection accuracy.

Introduction

Urban land-use research involving remote sensing often uses a broadbrush approach wherein every conceivable land-use class in the urban environment is analyzed. This study, however, focuses on the identification of single-family residential land-use development versus all other classes of urban information. It is even more specific in that it is based only on residential environments located at the urban fringe, i.e., that region which causes severe data collection problems for many administrators. The study strives to increase our understanding of the change in spectral and textural response as single-family residential housing develops through time.

Abstract: *Landsat multispectral scanner data were applied to an urban change detection problem in Denver, Colorado. A dichotomous key yielding ten stages of residential development at the urban fringe was developed. This heuristic model allowed one to identify certain stages of development which are difficult to detect when performing digital change detection using Landsat data. The stages of development were evaluated in terms of their spectral and derived textural characteristics. Landsat band 5 (0.6-0.7 μm) and texture data produced change detection maps which were approximately 81 percent accurate. Results indicated that the stage of development and the spectral/textural features affect the change in the spectral values used for change detection. These preliminary findings will, it is hoped, prove valuable for improved change detection at the urban fringe.*

There is a critical need for such information. For example, the U.S. Bureau of the Census must perform a decennial update of more than 300 Standard Metropolitan Statistical Areas in order to identify the outer limit of the urbanized area (Christenson and Lachowski, 1976). Digital change detection algorithms using Landsat data may support this update procedure (Stauffer and McKinney, 1978; Royal, 1980; Toll *et al.*, 1980). However, the spectral and textural nature of the single-family residential development has not been fully documented (Riordan, 1980; Jackson *et al.*, 1980; Jensen, 1980). More information is needed on the spectral response of various stages of residential development before operational change detection is possible (Jensen, 1981).

The U.S. Geological Survey (USGS) is also interested in improved knowledge about the spectral nature of residential land-use development (Place, 1977). The agency hopes to use imagery from improved sensor systems to obtain base line urban Level II land use information for the 1:250,000 and 1:100,000 scale nationwide mapping program. The USGS has repeatedly stated that results from analysis of digital Landsat data are used as supplementary rather than primary suburban land-use information (Loelkes *et al.*,

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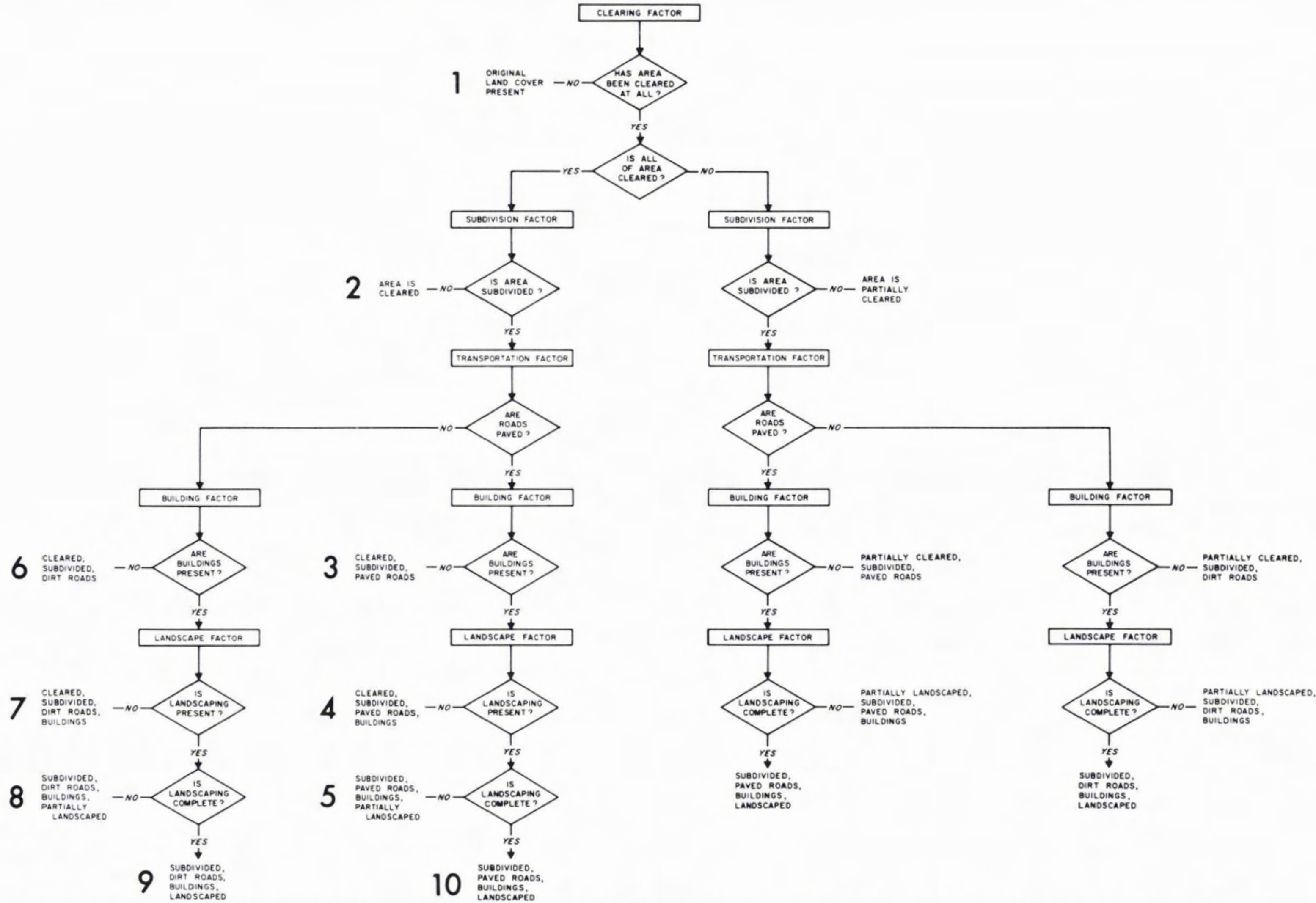


FIG. 1. A dichotomous key used to identify progressive stages of residential development. Such development in Denver, Colorado, normally begins by clearing the terrain of vegetation prior to subdivision. In many geographic areas such as the eastern and southeastern United States, however, some natural vegetation is usually left as landscaping. The absence or existence of natural vegetation dramatically affects the range of signatures that a parcel of land undergoes as it progresses from natural vegetation to fully landscaped residential housing. Consequently, only the left half of the key was used in this analysis. The developmental stage concept is used in this paper to identify specific land covers that are difficult to detect using digital change detection methods.

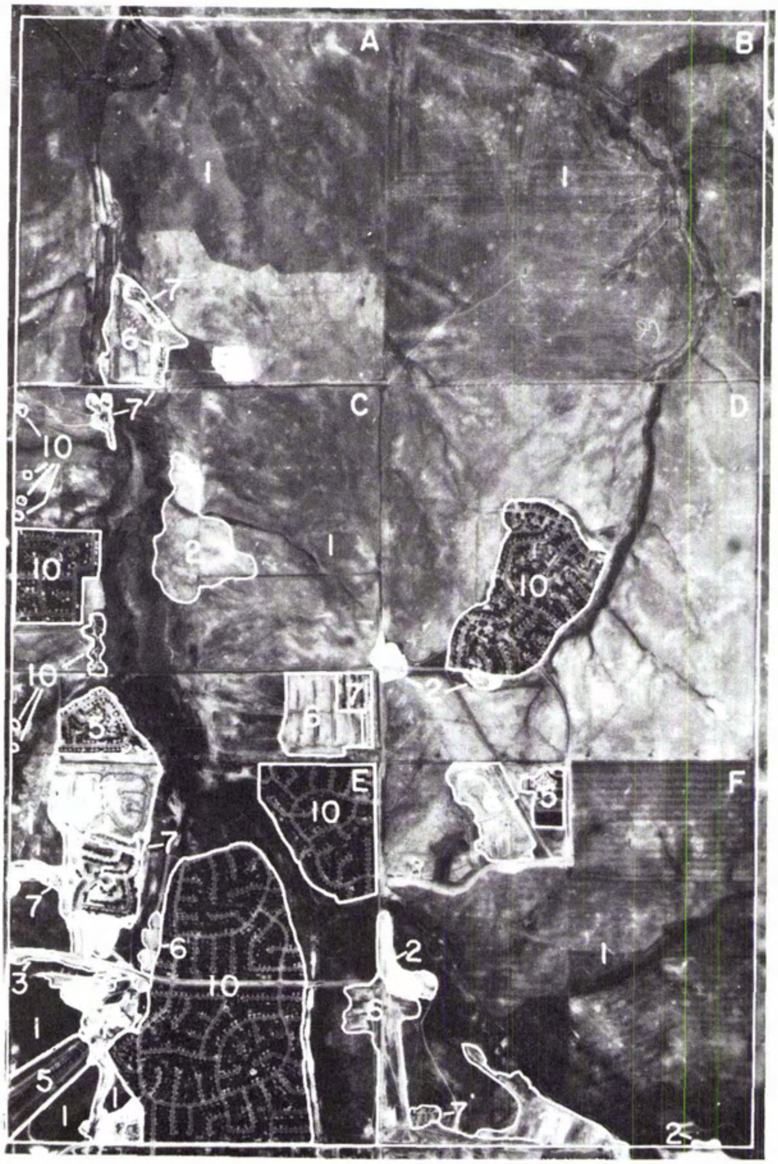


FIG. 2. Panchromatic aerial photography of a portion of the Fitzsimmons 7½-minute quadrangle near Denver, Colorado, on 8 October 1976. Photography was obtained from Colorado Aerial Photo Service of Denver, Colorado. The original scale was 1:52,800. The land cover was manually interpreted and classified into ten stages of residential development using the logic of Figure 1.

1979). However, with their stated goal of producing land-use *change* maps every five years for most urban areas in the United States, the ability to accurately inventory the single-family residential land use from satellite multispectral sensors takes on significance (Anderson, 1977; Milazzo, 1980).

Finally, many local and regional decision makers require information on how land is being converted from agricultural or natural vegetation into residential land use (Vink, 1975; Miller and Miller, 1976; Rubingh and Carlson, 1979). Thus, results of this research may also aid regional urban land-use change detection studies.

The Nature of the Problem

Error associated with current land-use change detection at the urban fringe may be associated with an oversimplification of the problem. For in-

FIG. 3. Panchromatic aerial photography of the study area obtained on 15 October 1978. The original scale was 1:57,600. Comparison with Figure 2 reveals substantial residental land use development since 8 October 1976.

stance, it is often assumed that the dates used in the change detection analysis will capture a parcel of land at the beginning (e.g., natural vegetation or agriculture) or ending point (e.g., fully landscaped residential) along a development continuum. In reality, the parcel of land may be at any point within the development sequence on either date.

Based on an awareness of this phenomenon, a heuristic model was created to identify stages of residential development through which a parcel of land might progress (Figure 1). This model was based on characteristics observed in a six square mile portion of the Fitzsimmons 7½′ quadrangle near Denver, Colorado, where substantial residential development took place between October, 1976, and October, 1978.

The stages of residential development were determined by examining a parcel of land in terms of five factors, i.e., clearing, subdivision, transportation, building, and landscaping. In semi-arid

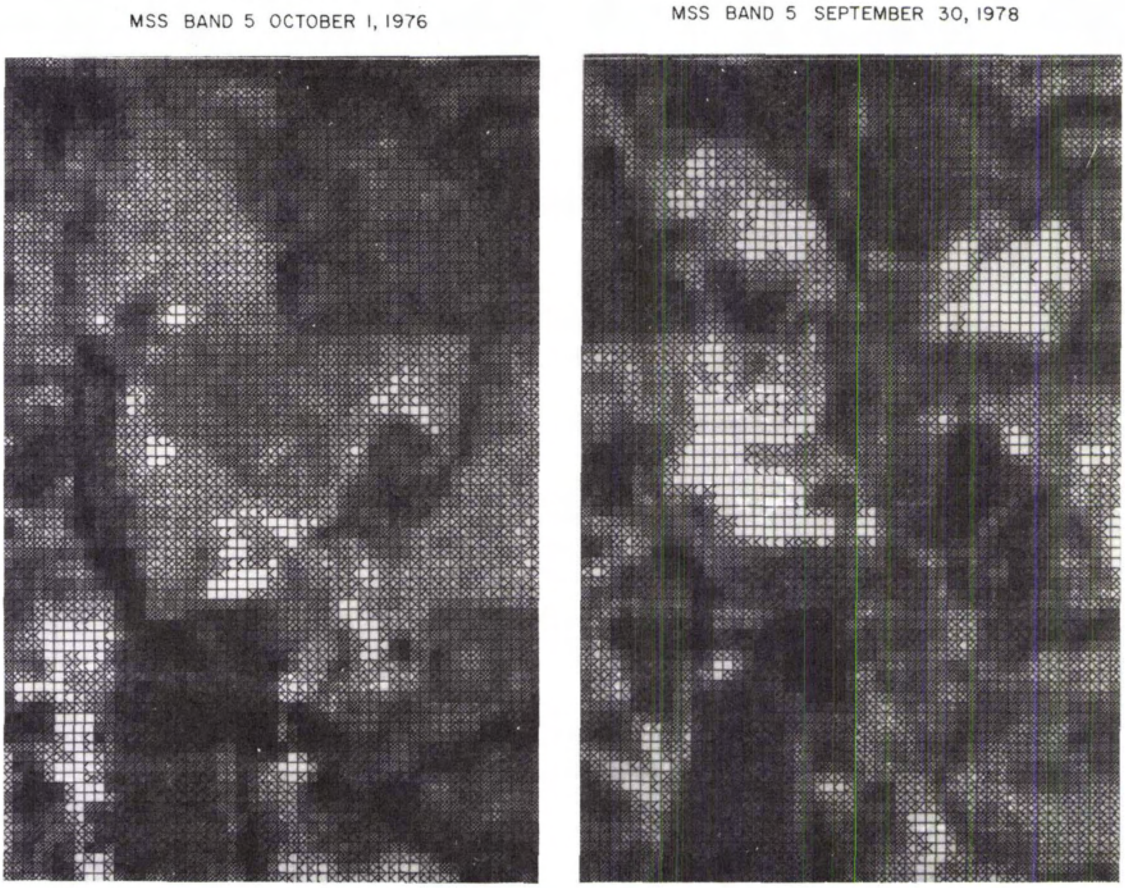


FIG. 4. Landsat MSS band 5 images of a portion of the Fitzsimmons Quadrangle study area obtained on 1 October 1976 and 30 September 1978. Raw data were used in all change detection whereas these figures have been contrast stretched.

environments such as Denver and much of the southwestern United States, development normally begins by clearing the terrain of natural vegetation prior to subdivision. In other geographic areas such as the East and southeastern U.S., some natural vegetation is usually left as landscaping. The absence or existence of natural vegetation dramatically affects the range of signatures that a parcel of land undergoes as it progresses from natural vegetation to fully landscaped residential housing. Consequently, only the left half of Figure 1 is used for this study area. Site engineering associated with lot subdivision may produce changes in reflectance as the soil is graded, compacted, and often terraced for development. The transportation network in a new development may account for as much as 20 percent of the ground cover. Also, whether the roads are bare soil or paved (concrete or asphalt) will influence the spectral reflectance. Buildings (rooftops) account for approximately 30 to 40 percent of the tract surface area and have a significant effect on the integrated pixel value. Finally, a distinction is made as to whether the parcel is unlandscaped, partially landscaped, or completely landscaped. In this semi-arid environment, lawns and shrubbery have a significant impact on spectral response.

Using these criteria, panchromatic (0.4-0.7 μm) aerial photography of the study area obtained on 8 October 1976 and 15 October 1978 (Figures 2 and 3) were visually interpreted to identify single-family residential development in the ten possible stages (see Figure 1). A substantial amount of land use in the 1978 image is in stages other than 1 and 10. Stages 8 and 9 (i.e., subdivided, dirt roads, buildings, and partially landscaped; and subdivided, dirt roads, buildings with landscaping) were not present in the data set. It is suggested that residential change detection procedures based on remotely sensed data should attempt to

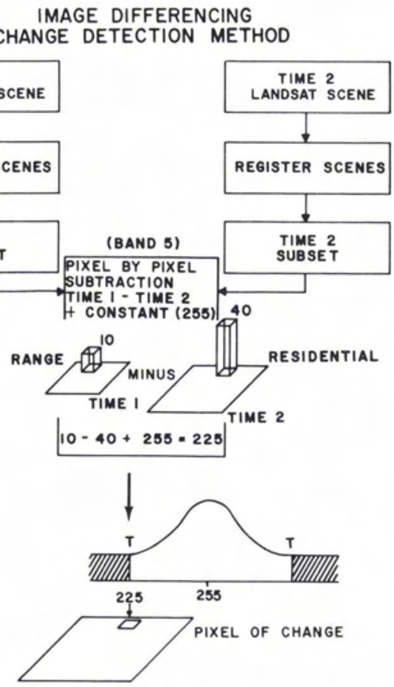


FIG. 5. The image differencing change detection method.

understand the spectral and textural nature of these various stages which might be encountered. In this manner, optimum sensor system configurations and change detection algorithms or procedures might be identified.

Each of the stages of development were easily identified using the 1:50,000 panchromatic stereo aerial photography. Unfortunately, multiple date aerial photography is often available only at substantial cost and then rarely in a format such that the multiple dates can be examined quantitatively to detect change (Adeniyi, 1980). Consequently, it will be useful to determine the contribution which digital Landsat data can make to an analysis of stages of residential development at the urban fringe. It is believed that the Landsat 1, 2, and 3 MSS configurations are useful only for regional or national change detection endeavors. It will take improved spatial and spectral resolution such as that proposed for Landsat D (National Academy of Sciences, 1976; U.S. Geological Survey, 1980) to achieve detailed local change detection. The 18-day temporal resolution, however, is probably sufficient for most urban change detection tasks.

METHODOLOGY

In order to understand how Landsat digital data might contribute to accurate residential change detection at the urban fringe, it was necessary to

- identify the landsat images to be used;
- identify specific spectral and textural features to be analyzed;
- identify the change detection algorithm to be applied;
- assess the accuracy of spectral or textural change detection maps of the study area; and
- evaluate the nature of the spectral and textural change in response through time.

IMAGERY

The Landsat MSS obtained images of the Fitzsimmons quadrangle on 1 October 1976 and 30 September 1978. The imagery was registered to a UTM projection using ground control points. Pixels were resampled to 60 m^2 using a cubic convolution algorithm for resampling data (Van Wie and Stein, 1976). Image processing was performed using an interactive image processing system (Jensen *et al.*, 1979).

IMAGE CHARACTERISTICS

It is generally believed that band 5 (0.6-0.7 μm) data enhance the contrast between vegetated and nonvegetated surfaces because of the chlorophyll absorption of red radiant flux by green vegetation (Colvocoresses, 1977; Swain and Davis, 1978). In western semi-arid environments, band 5 proved slightly superior to all other bands for binary

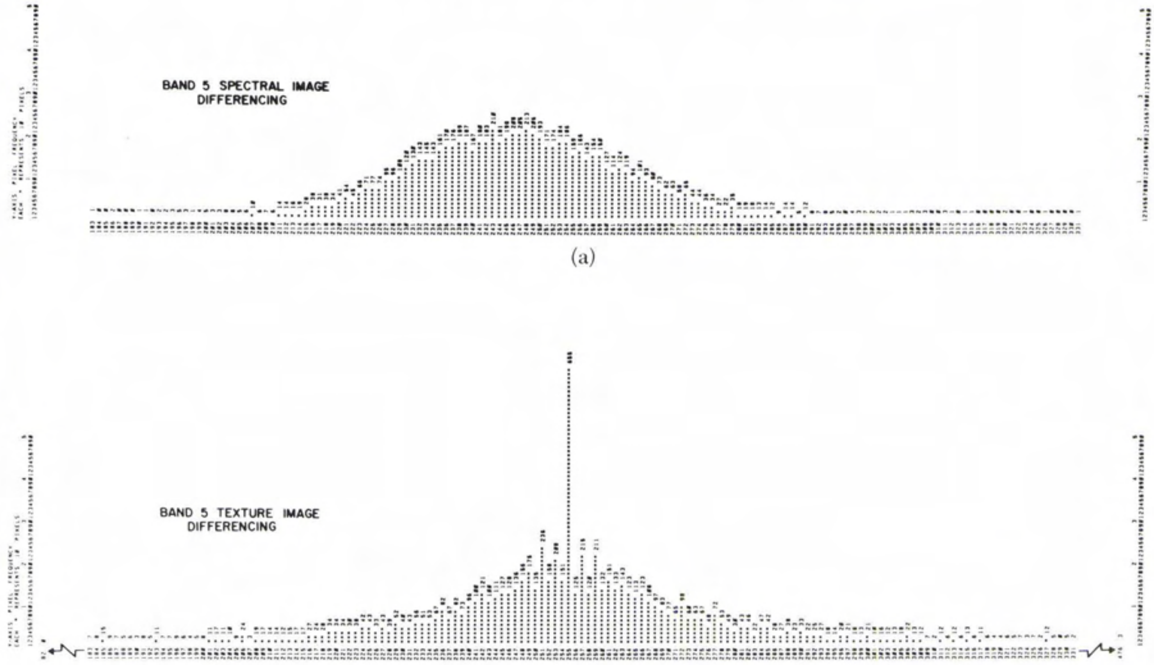


FIG. 6. Histograms produced by differencing original or preprocessed Landsat digital data for Date 1 and Date 2. Histogram (a) was produced using raw MSS band 5 spectral values. Histogram (b) was produced using preprocessed texture values. Change maps were produced by analyzing each histogram and selecting appropriate threshold values in the lower and upper tails of the distributions. A density slicing procedure was then applied that annotated as change pixels all those lying beyond the thresholds.

Landsat change detection (i.e., change versus no-change) at the urban fringe (Toll *et al.*, 1980; Royal, 1980). In addition, band 5 proved far superior for change detection in more heavily vegetated areas such as Virginia (Toll *et al.*, 1980). Based on these results, band 5 was selected as the most promising spectral band to be used in the change detection analysis of Denver, Colorado, suburban environments (Figures 4a and 4b).

Texture is very important in human interpretation of change in aerial photography (Shepard, 1964; Hajic and Simonett, 1976) and therefore offers the potential of improved accuracy when used as an element in machine-assisted change detection. There are numerous texture features which may be computed (Haralick, 1973; Tamura *et al.*, 1978; Hsu, 1980). A robust method of extracting textural information from spectral images involves the use of gray-tone spatial dependency matrices (Haralick, 1979). If $\delta = (\Delta x, \Delta y)$ is considered a vector in the (x, y) plane, for any such vector and for any picture $f(x, y)$, it is possible to compute the joint probability density of the pairs of gray levels that occur at pairs of points separated by δ. If there are only m gray levels, e.g., $0 \ldots, m$, this joint density takes the form of an array h_δ where $h_\delta\ (i, j)$ is the probability that the pairs of gray levels (i, j) occur at separation δ. This array, $\mathbf{M}_\delta$, is m by m in size. It is easy to compute the h_δ array for $f(x, y)$, where Δx and Δy are integers, by counting the number of times each pair of gray levels occurs at separation $\delta(\Delta x, \Delta y)$ in the picture. For example, consider the following image quantized to just four levels:

01123
00233
01223
12322
22332

If $(\Delta x, \Delta y) = (1, 0)$, then these numbers are represented by the gray-tone spatial-dependency matrix $\mathbf{M}_\delta$:

	0123
0	1210
1	0130
2	0035
3	0022

where the entry in row i and column j is the number of times gray value i occurs to the left of gray value j. It is assumed that all textural infor-

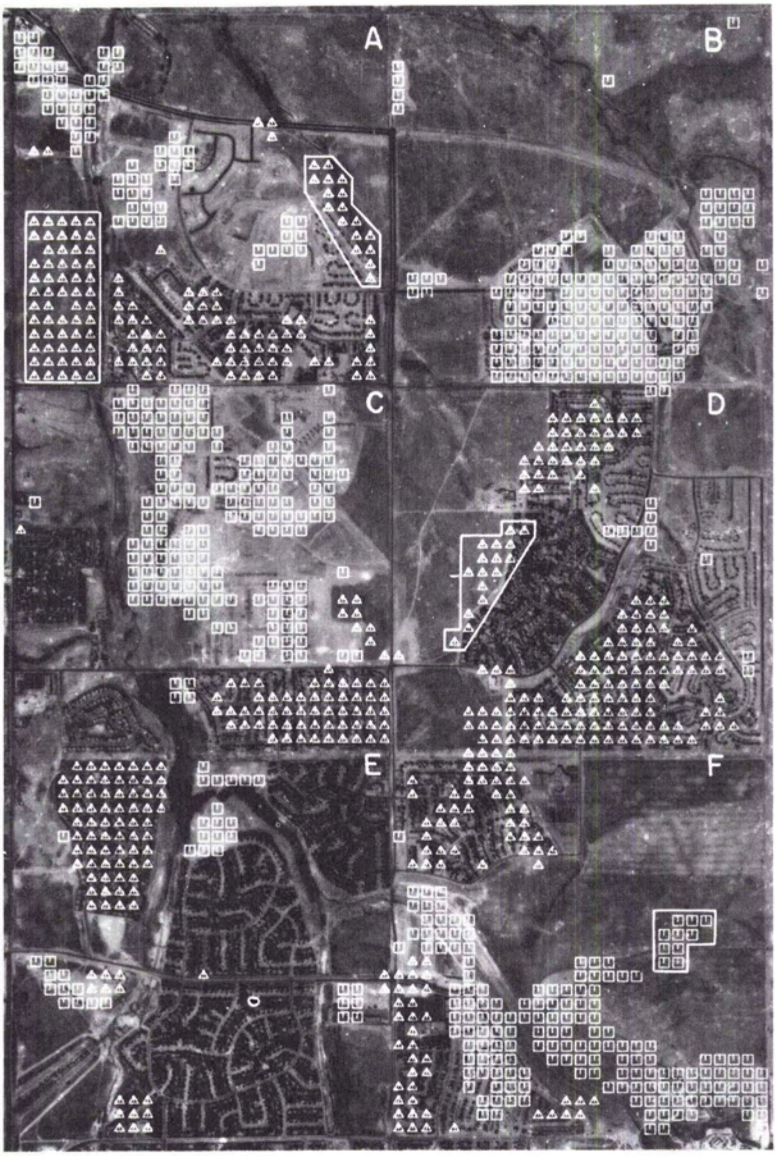


FIG. 7. A land-use change map produced using the band 5 image differencing method. The results are superimposed on the 15 October 1978 aerial photography. The two symbols represent pixels found in the lower or upper tails of the change histogram. Somer errors of commission are outlined.

mation is contained in the gray-tone spatial dependency matrices that are developed for angles of 0, 45, 90, and 135 degrees.

Haralick proposed a variety of measures to extract useful textural information from the $\mathbf{M}_\delta$ matrices. One of these is the Angular Second Moment (ASM),

$$\text{ASM} = \sum_{i=1}^{m} \sum_{j=1}^{m} \left[h_\delta(i,j)/R\right]^2,$$

where m is the set of possible gray tones, in this case 255; R is the number of resolution cell pairs; and $h_\delta(i,j)$ is the (i,j)th entry in one of the angular gray-tone spatial-dependency matrices previously discussed. During computation, four spatial gray-tone dependency matrices (0, 45, 90, and 135 degrees) are derived for each pixel based on neighboring pixel values. The average of these four measures was used to create the texture images. A 5 by 5 spatial moving filter centering on

TABLE 1. CHANGE DETECTION EVALUATION FOR DENVER, COLORADO (1976-78)†

a. Band 5 Spectral Image Differencing

	change	no change	
change	973	810*	absolute accuracy:
nc	175ᵀ	2,362	(973 + 2362)/4320 = 77%

b. Band 5 Spectral Image Differencing Plus Texture Differencing

	change	no change	
change	1,142	641*	absolute accuracy:
nc	180ᵀ	2,357	(1142 + 2357)/4320 = 81%

† These statistics were derived by comparing the results of Landsat digital change detection methods with a binary change/no-change map produced from the photointerpretations of the 1976 and 1978 panchromatic aerial photography.
* Errors of omission.
ᵀ Errors of commission.

each pixel was used in this analysis to extract texture information. Texture images were produced from band 5 of the 1976 and 1978 Denver, Colorado, data set.

THE CHANGE DETECTION ALGORITHM

After studying various change detection algorithms (Lillistrand, 1972; Weismiller *et al.*, 1977; Todd, 1977; Robinson, 1979; Friedman, 1980; Malila, 1980; Jensen, 1981), the image differencing method was selected. Previous research indicated image differencing provided lower change detection errors when compared against other approaches (Toll *et al.*, 1980; Ingram *et al.*, 1981). Image differencing involves subtracting the imagery of one date from that of another. The subtraction results in positive and negative values in areas of radiance change and zero values in areas of no change. In an 8-bit (2^8) analysis with pixel values ranging from 0 to 255, the potential range of difference values is -255 to $+255$. The results are normally transformed into positive values by adding a constant, c. The operation is expressed mathematically as

$$\Delta x_{ijk} = x(1)_{ijk} - x(2)_{ijk} + c$$

where

Δx = the change pixel value;
$x(1)$ = value at time 1;
$x(2)$ = value at time 2;
c = a constant, e.g., 255;
i = 1 . . . nl number of lines;
j = 1 . . . nc number of columns; and
k = a single band, e.g., band 5.

This procedure yields a "differenced" distribution for each band (Figure 5), where pixels of minor radiance change are distributed around the mean while pixels of significant change are distributed in the tails of the distribution.

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. Often, a standard deviation from the mean is selected and tested empirically to determine if changes were accurately monitored (Robinson, 1979). The procedure has recently become interactive, wherein a person familiar with the area tries various thresholds until optimum ones are identified (Royal, 1980).

A change histogram for band 5 image differencing of the Denver, Colorado, data set is shown in Figure 6a. Interactive analysis of the change histogram produced a change map which was superimposed as precisely as possible onto the 1978 aerial photography (Figure 7). Comparison of manually interpreted categories (Figures 2 and 3) with the digital change map (Figure 7) revealed interesting relationships. First, the digital method accurately identified land-use change from natural vegetation (category 1 in Figure 1) to partially- (category 5) or fully-landscaped residential development (category 10) in sections A, C, D, and E. However, in sections A and C there was substantial omission error when change was from natural vegetation to categories 3, 4, or 6, i.e., when development was initiated but not completed. Evidently, the procedure, or the band, was inadequate for discriminating between the spectral response of these developing land covers and the unirrigated rangeland present at this time of year. Errors of commission occurred in sections A, D, and F (see outlined areas) where some natural vegetation was improperly classified as undergoing change. Two factors may be responsible for this apparent change. First, Denver received slightly less precipitation in September of 1978 than in September of 1976. Second, we hypothesized there may have been phenological or biomass changes between dates which may cause the spectral response of such land to change, although it remains the same with respect to land cover. The absolute accuracy of the classification was 77 percent with the majority of the error being omission (statistics are summarized in Table 1, part a).

These and other results (Weismiller *et al.*, 1977; Riordan, 1980) suggest that image differencing of spectral data (band 5) may be too simple a procedure to deal adequately with all types of change taking place in a complex residential scene.

The 1976 and 1978 texture images were differenced and the histogram (Figure 6b) analyzed to produce a change map showing areas where texture changed dramatically between 1976 and 1978 (Figure 8). Note that the texture change map com-

FIG. 8. A land-use change map produced using the texture differencing method. Some new areas of residential development are correctly identified (outlined); however, considerable change from natural vegetation to partially- or fully-landscaped residential is omitted. Consequently, it is preferable to use this method in conjunction with other methods (see Figure 9).

plemented rather than duplicated information provided in the change map derived from spectral characteristics (Figure 7). The texture change map accurately identified many pixels of developing residential land use, especially conditions 4 and 6 in sections A, C, and D (outlined areas in Figure 8). Unfortunately, change in land use from rangeland (category 1) to established residential (category 10) occasionally produced no significant change in texture, resulting in these areas not being identified. Possible reasons for this condition are discussed in the following sections. Thus, the texture change map complemented the spectral change map and should be used in conjunction with it, not alone. The differenced band 5 (Figure 7) and the texture change map (Figure 8) were combined into a single change map (Figure 9). The absolute accuracy of this change map was 81

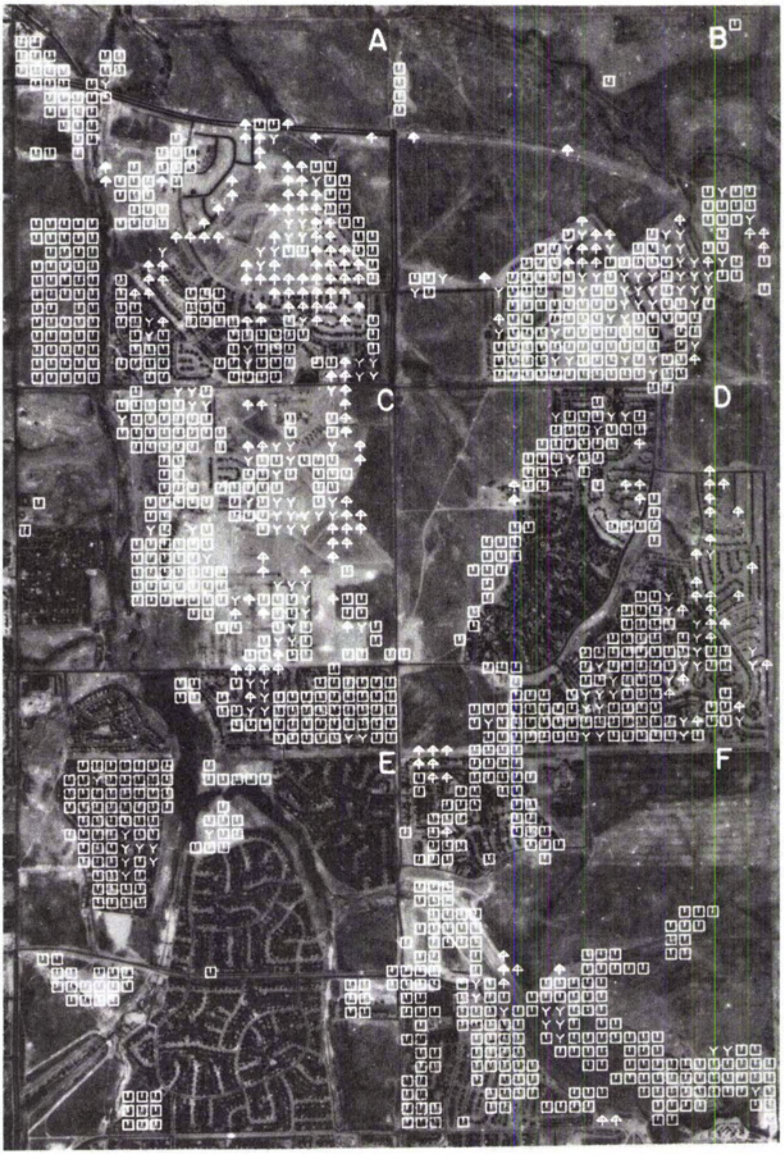


FIG. 9. A land-use change map produced by combining the band 5 image differencing change map (Figure 7) and the texture change map (Figure 8). Pixels classified as change by the band 5 image differencing are symbolized with a box while those classified as change by the texture method are shown as an arrow. Pixels classified as change by both methods are symbolized with a "y" representing "yes". Note that the two change maps complement one another.

percent. The 4-percent increase was due to fewer omission errors (refer to Table 1, part b).

SPECTRAL AND TEXTURAL CHARACTERISTICS

An evaluation of the spectral and textural response of residential development stages was performed to appreciate how signatures vary through time. Previous research in this study area revealed that several of the developmental stages were redundant at the 79 m ground resolution of Landsat (Jensen, 1981). Consequently, the ten stages were aggregated to five as follows:

New Number	Stage of Development
1	1 rangeland/agriculture
2	2, 3, 6 cleared, subdivided, roads
4	4, 7 cleared, subdivided, roads, buildings
5	5 partially landscaped
10	10 fully landscaped

Stages 8 and 9 were not present in the study area. Statistics from each of the five aggregated stages of development (1, 2, 4, 5, and 10) were obtained from both band 5 and band 6 of the 1976 and 1978 Landsat imagery. Texture values for these same sites were collected from the 1976 and 1978 texture images. All statistics were obtained in a supervised manner due to the improbability of obtaining at least 40 pixels per stage of development using a random sampling design.

The data are displayed graphically as two- and three-dimensional parallelepipeds in Figure 10 (Jensen, 1979). Analysis of where the stages of development cluster in three-space (band 6, *X*-axis; band 5,*Y*-axis; and texture on the Z-axis) provide insight into the nature of both spectral and textural change as a function of residential development stage.

With the 1976 band 5 and band 6 statistics displayed in Figure 10A, notice the separation which exists between most stages with the exception of rangeland (stage #1) and partially landscaped residential (stage #5). In 1978, there is still overlap between stages 1 and 5; however, the more serious problem is the complete overlap of stages 2 and 4 (Figure 10A′). Note in both dates the modest contribution of band 6 to separability. Band 5 accounts for the majority of the separation.

As the parallelepipeds are viewed from 0, 60, and then 90 degrees, the importance of the texture information becomes apparent. The edge-on view of 1976 band 5 and texture data shown in Figure 10C demonstrates that, although there is still some overlap between stages 1 and 5, there is substantial textural difference between these two classes. The most pronounced texture contribution, however, is shown in Figure 10C′ where the texture provides complete separation of stages 2 and 4 when used in conjunction with band 5 data. Stages 1 and 5 are completely disjoint for this 1978 image.

To gain additional insight, the mean values of each of the five stages of development for band 5, and 6, and texture in 1976 and 1978 are plotted in

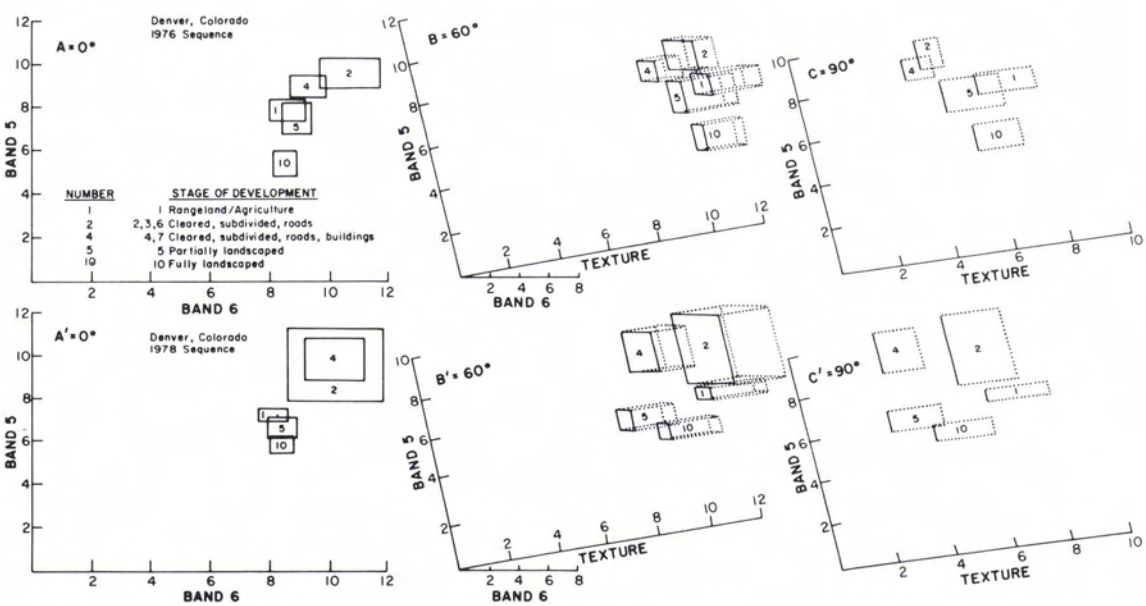
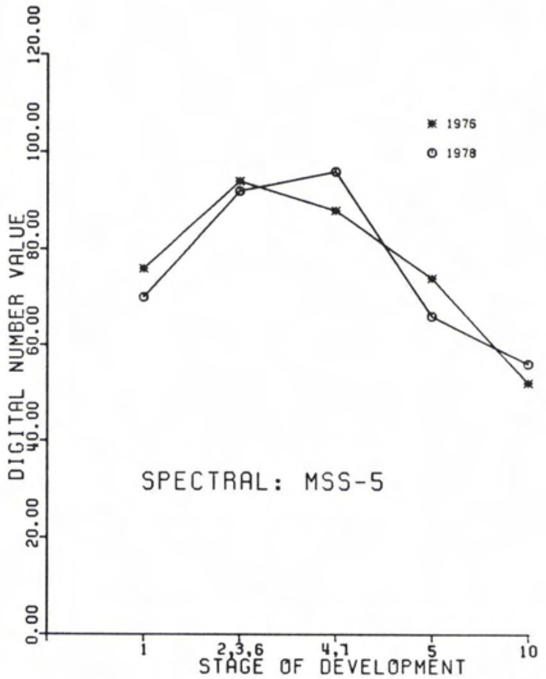
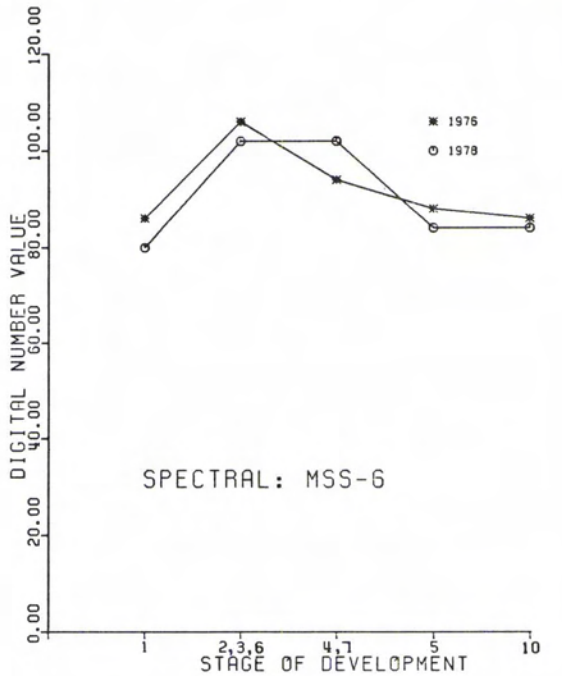


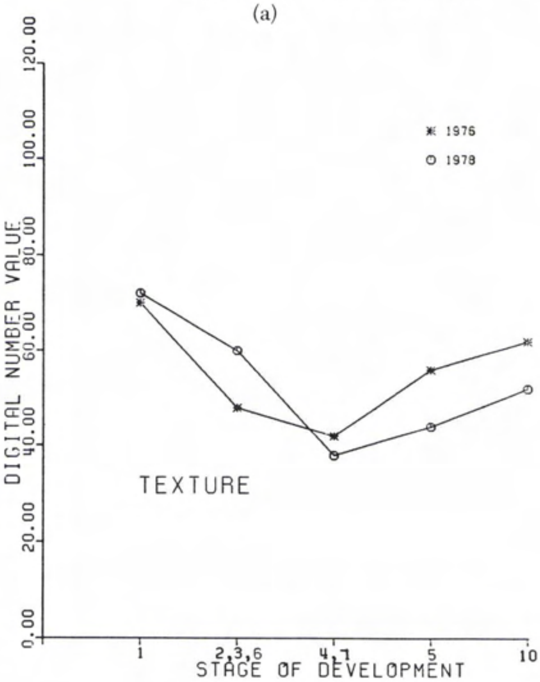
FIG. 10. Stages of residential development at the urban fringe displayed using parallelepipeds of spectral (MSS-5, MSS-6) and textural statistics obtained from 1976 and 1978 Landsat imagery of the Fitzsimmons quadrangle near Denver, Colorado. The parallelepipeds were constructed using the mean ± one standard deviation for each spectral or textural feature and each of the five stages of residential development. The top row provides the 1976 statistics rotated from 0 to 60 then 90 degrees and the bottom row presents the 1978 statistics. Of particular importance is the counterclockwise stage of development pattern found when band 5 and texture are plotted together in C and C′. Also, note the degree of separation between stages especially in the 1978 data, i.e., in C′.



(a)



(b)



(c)

FIG. 11. Spectral (MSS-5, MSS-6) and textural digital number (DN) values plotted as a function of stage of residential development. The mean values for each stage are plotted using statistics obtained from the 1976 and 1978 Landsat imagery of the Fitzsimmons quadrangle near Denver, Colorado. Note the general trends which exist, particularly in the MSS-5 and texture data.

Figure 11. For band 5 data (Figure 11a), the pattern appears to be one of increased reflectance of red radiant flux as the scene progresses from rangeland (#1) to cleared land (#2). Stage 4 produces a higher DN value in 1978 than 1976 for no documentable reason. Then, as the area becomes partially (#5) and then fully landscaped (#10), the chlorophyll absorption of the red radiant flux by the vegetation causes the DN values to decrease. In fact, because the residential grass and trees are assumed to be watered and more luxuriant than the dry, unirrigated rangeland, the DN values drop below that of the initial rangeland condition.

In the band 6 comparison, clearing (#2) causes the reflectance of infrared radiant flux to increase due to the exposure of sandy, bare soil (Figure 11b). Stage 4 again yields a higher DN value in the 1978 image. Then, the landscaping stages (5 and 10) bring the reflectance back down to a level approximately equal to that of the original rangeland (#1) condition.

The textural progression of the 5 stages of development are also shown (Figure 11c). Generally, the higher the DN value the more homogeneous or smooth the texture. The initial rangeland condition (#1) appears relatively smooth. Development to stages 2 and 4 produces a more coarse texture with stage 4 being consistently more coarse on both dates. As landscaping ensues, the texture becomes progressively more smooth. It is assumed that, at some date later than the two year time framework analyzed here, the fully landscaped residential stage (#10) will approach the relatively smooth texture of the rangeland condition (#1). Additional research should document this condition for various environments.

Conclusions

The stages of development discussed in this paper have been shown to be of value in understanding the nature of residential growth at the urban fringe. Spectral and textural information about the existence of these stages is obtainable from remote sensing devices. In this research, band 5 (0.6-0.7 μm) Landsat spectral data and derived texture data provided complementary information, and when used together increased change detection accuracy. The primary contribution of texture data was the measure of class heterogeneity. Specifically, texture data improved upon the detection of intermediate stages of residential development, particularly stages 4 and 6 in model. Texture data alone, unlike raw spectral data, did not adequately detect change from natural vegetation to either partially or fully landscaped residential areas. These results were derived using data obtained over Denver, Colorado, and are characteristic of land-cover situations found in the southwestern United States. Other research should emphasize different geographic areas such as the East and southeastern United States.

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