EXPERIMENTAL APPLICATIONS OF MULTIBAND PHOTOGRAPHY IN URBAN RESEARCH

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ABSTRACT. — Planning and research within the urban area are placing increasing demands on urban data which cannot be met by existing sources. As a result, considerable recent interest has been shown in remote sensors as a possible source for satisfying some urban data needs.

Three studies in experimental applications of one of these sensors, the multiband camera, to urban data problems are reported. The first discusses visual interpretation of housing quality from associated environmental characteristics. The second is concerned with the identification of road surfaces by spectral signature, a procedure which will form the basis of subsequent automated surface identification. The final experiment illustrates a method of automated data retrieval from a set of multiband photographs.

In recent years, increasing interest has been shown in remote sensors as a means for investigating a variety of phenomena. Remote sensors are instruments which record data about objects while located at some distance from those objects. They may be carried on the ground, on aircraft, or on satellites. The conventional camera which takes photographs of phenomena (people, things, etc.) is an example of a remote sensor.

One area in which remote sensors will play a critical role in the near future is in the analysis of urban phenomena. Scientists face an ever-widening gap between information regarding urban land use that is needed and that which is available using present data collection procedures. Three empirical studies are described. They provide a stimulus for more intensive research by indicating how important contributions may be made to both theory and planning within the urban area.

Experimental studies at Northwestern have been mainly concerned with the interpretation of the returns from one specific sensor, the multiband camera. Other available sensor returns have been neither as numerous nor of the quality of the multiband camera photographs.

In conventional aerial photography, one image is produced recording the radiation reflected from the imaged surface. The wavelengths of this radiation lie between 0.4 and 0.7 microns (the visible band of the electro-magnetic spectrum). In multispectral photography, several simultaneous images of the same set of objects are produced, each image recording returns for a separate part of the "visible" and "near visible" spectrum (the normal range of such a system is from 0.4 to 0.9 microns which includes the near infrared).

We may recognize two categories of data that can be extracted from imagery:

i) data relating to phenomena which are directly observable on the imagery.

ii) data relating to phenomena whose existence has to be inferred from the presence of other features on the imagery which are known to be consistently associated with these phenomena.

The extraction of these data can be undertaken using either visual or automated interpretation methods.

The compilation of inventories from direct visual interpretation has received considerable attention in the literature. Although most of this material is concerned with the use of conventional aerial photography, the same results can be obtained with multispectral photography. In some cases, the results may be improved, as specific phenomena may be more readily identified by their level of energy radiation within narrow bands of the electro-magnetic spectrum.

The acquisition of the second type of data, compilation of 'inventories by surrogate', has received less attention. It forms the focus of the first study, in which a method of evaluating housing quality from multispectral photographs is outlined. The second and third studies are concerned with the factors involved in automated interpretation in the urban area; the second illustrates a pattern recognition technique, while the third outlines a method of automated data extraction and graphic display.

The instrument used to obtain the imagery for the empirical work was an Itek nine-lens multiband camera.[1] This camera comprises nine six-inch Leighty High-Resolution lenses, each with a 21° square field of view. The nine shutters are synchronized to function simultaneously so that the same ground area is imaged in each case. Gelatin filters are employed with each lens to restrict the recorded returns to specified wavelength bands. Six of the exposures are on two rolls of 70mm. panchromatic film and the remaining three on one roll of 70mm. infrared film; the spectral range of the nine images is from 0.4 to 0.9 microns. The wavelength band associated with each of the nine frames is given in Table 1.

Visual Interpretation: The Evaluation of Housing Quality[2]

Determination of the spatial distribution of different grades of housing quality is of considerable importance in the field of urban planning and research. Where public health and welfare are concerned, the identification of areas where standards are low is particularly relevant. Current methods of evaluation are time-consuming, expensive, and subject to considerable error. If remote sensing devices can provide a major portion of the required information, and, in so doing, reduce overall expenditures, an important service will have been performed.

Table 1: Multiband Camera Spectral Bands.

Lens No.	Bandwidth (mu)
1	400-500
2	450-510
3	520-550
4	550-600
5	590-640
6	670-720
7	700-810
8	810-900
9	Full sensitivity range of IR film

The study recognized that housing quality cannot be directly measured from the air, since quality of housing depends not only on external features of the dwelling and immediate environment, but also on the internal condition of the structure. Nevertheless, it was hypothesized that these internal characteristics are consistently associated with other external criteria that may be imaged from a remote sensor. The verification of such a hypothesis would facilitate the development of a rapid and efficient survey method by which areas having the highest probability of possessing low quality housing could be readily identified.

Fifteen small areas in the Chicago region, each corresponding to one multiband sequence, were chosen for detailed study. Inferences were made about the housing quailty in each area on the basis of the following criteria: land crowding, non-residential land uses, private open space, hazards and nuisances associated with the transport system, public utilities, and the presence of basic community facilities.

Although most of the above features can be identified on conventional aerial photographs, it was often found that a given phenomenon could be distinguished much more readily on one band than on any other. More significantly, some factors, which were found to be consistent indicators of poor housing quality, were not readily identifiable on any plate within the visible spectrum, but stood out clearly in the bands of the photographic infrared. The more important of these are listed below:

1. *Private Landscaping.* In the better quality housing areas, landscaping in the form of shrubs, rock gardens, flower beds, etc., is common to almost every lot. The opposite tends to be true in the poor quality areas, although occasionally a lot supporting a single-family dwelling in an area of predominantly poorer quality multiple-unit structures will exhibit some landscaping. This information is more readily obtained from the photographic infrared. The infrared also helps to differentiate grass and dirt. Grass-covered front and back yards are found in good quality housing areas, while in poorer areas, dirt rather than grass is evident. Where grass does exist in poorer districts, it is not as healthy or well-conditioned as in the better quality housing areas, and tends to be patchy in appearance. In addition, the photographic infrared clearly reveals footpaths crossing both occupied and vacant lots in the low quality housing areas.

2. *Public Landscaping.* Parkways (strips between streets and sidewalks) are the property of the city. However, the property-owner is obligated to care for that segment of the parkway which fronts on his property. In the better areas, this strip is invariably grass-covered and well-kept, comparable to the condition of the owner's private lawn. In the poorer quality housing areas the parkway is usually a strip of dirt. A few small, widely-spaced trees are found on the better-kept of these blocks. Structures in these areas are frequently multiple-family, so there may be some question as to whether the landlords or tenants are remiss in maintaining the parkways.

3. *Vacant Lots.* In the areas of better quality housing vacant lots are well-tended. The converse is true in poor quality areas. This difference may be due to the stronger influence of factors such as neighborhood pride, pressure from neighbors, and enforcement of city by-laws in higher quality residential areas. The photographic infrared clearly differentiates between grass, weeds, and bushes; in addition, litter may be more readily identified on the infrared than on returns from the visible portion of the spectrum.

4. *Curbing.* In areas of better quality housing the curb line is unbroken on all blocks. In the poorer quality areas, the curb line is frequently broken, as a result of cars being parked on parkways or front yards, or has not kept pace with building. The photographic infrared imagery reveals this feature more readily and reliably than the visible imagery.

Study of the fifteen areas using multiband imagery has led to some tentative statements as to those features which are most commonly associated with the occurrence of poor quality housing. These were found to be:

i) the presence of litter, garbage, wrecked or derelict cars, and piles of lumber and rubbish throughout a neighborhood, on both occupied and vacant lots. In the study area this proved to be the best single indicator of low quality housing.

ii) a lack of landscaping in yards and parkways together with the presence of weeds on vacant lots.

iii) the number of vacant lots.

iv) the existence of non-residential

hazards and nuisances, primarily industrial plants and warehouses.

v) the extent of lot-crowding, i.e., the amount of open or play area that exists on the residential lots.

In exploring the validity of the above technique it is instructive to compare the evaluation procedure with that used by the American Public Health Association (APHA).[3] Of the 24 items contained in the APHA environmental survey appraisal form, 20 can be estimated for small areas using multiband photographs. In addition, 10 items not included in the APHA survey form were found to be consistent indicators of low quality housing in the Chicago multiband study.

It is possible that the Bureau of the Census will rely heavily on the APHA appraisal form for providing environmental data in the 1970 or 1975 Census. If the form is adopted, the multiband technique will gain added significance since it could provide data on rapidly changing housing patterns that would be compatible with data obtained on a regular basis by the Census. The Census data would also provide ground truth which could be used to check for systematic errors in interpretation.

The extent to which multispectral photographs can replace the field enumerator has yet to be established by controlled experiment. A point to be made is that the socioeconomic background and experience of the enumerator is an important source of error in existing data; the employment of experienced photointerpreters would help to greatly reduce this variation, not only because of superior training but also because fewer persons are involved in data acquisition.

A. The Classification of Road Surfaces[4]

Urban transportation provides an exciting field for the potential application of remote sensing. Possibilities for use of both active and passive sensors range from continual updating of maps of the transportation network to inventories of rolling stock and the monitoring of traffic flows in real time. The utility of any one sensor depends on its particular characteristics: in the case of multispectral photography, the ability to distinguish between different surfaces on the basis of their patterns of spectral reflectivity suggests that the classification of road surfacing materials might prove a profitable avenue of research. This could possibly form the first step toward a system which not only provides an inventory of surfacing characteristics for a city but also indicates the state of repair of that surface, pinpointing those areas in need of attention.

Sets of photographs for the North suburban areas of Evanston, Glenview, and Wilmette were obtained from a flight over Chicago in 1965. These are compared with maps compiled from a concurrent ground survey.

Since unpaved and paved roads can be readily distinguished on conventional photographs, attention was focussed on the latter category. Four different surface types were recognized in the ground survey:

1. bituminous asphalt
2. asphaltic concrete
   asphalt concrete
3. new concrete
4. old concrete

Visual inspection of the prints indicated that certain bands were more useful for distinguishing between these surfaces than others. For example, the greatest contrast between asphalt and concrete was to be found in the 0.55-0.60 micron range. Although the simultaneous visual comparison of several images is difficult, it did appear that the differences between band 4 (in the visible spectrum) and band 7 (in the near infrared) might provide a basis for discriminating between asphaltic concrete and bituminous asphalt. The evidence was sufficiently encouraging to justify further investigation.

Thirty-eight sample points on the images were chosen to cover the full range of surface types within the study area. Digitized values for these points were obtained by visual comparison with a Kodak Gray Scale on five of the nine available bands (Nos. 1, 2, 4, 7, and 8). Thus for the *i*th point we may define a vector X_i, where

$$X_i = (x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5}) \quad i = 1, 2, \ldots, 38$$

The x_{ij} are the individual tonal values for the *i*th point.

How may we determine the organization existing in this data set? One method is to consider X_i to define a point in five-space (with coordinates $x_{i1}, x_{i2}, \ldots, x_{i5}$). The distance from the point defined by X_i and that defined by X_j $(= d_{ij})$ may then be defined as

$$d_{ij} = \sum_{k=1}^{5} (x_{ik} - {}_{jk})^{2}\ {}^{\frac{1}{2}}$$

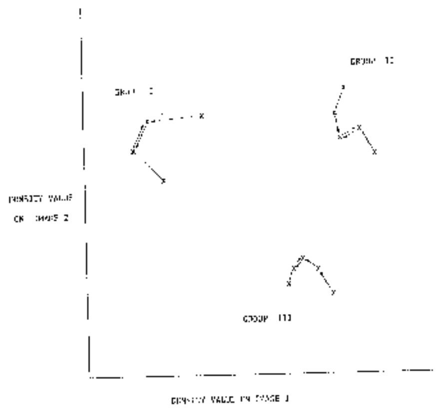

FIGURE 1.—Elementary linkage analysis in two-space.

Computation of the distances between all pairs of points yields a symmetrical matrix (with 38x38 elements in this case). Each of the distances indicates the "closeness" of two points in five-space; this would seem to be an important measure as we are concerned with the way in which the points form groups or clusters.

A simple way of subdividing the points into groups is to perform an elementary linkage analysis[3] on the distance matrix, such that each point is connected to its nearest neighbor. Figure 1 illustrates how such groups may be formed in two-space. In this way the basic organization of the data is identified; real world surfaces which are associated with these groups may then be established. Table 2 gives the results of this operation for the sample set of road surfaces.

The grouping procedure reveals important underlying patterns of associations between the signatures:

1. Bituminous asphalt is clearly separated from all other surfaces.
2. New and old concrete as a single category is well differentiated from the others; however, even within this classification some differentiation between old and new concrete may be possible. Group VI contains no new concrete, while the largest group, II, contains only two old concrete surfaces out of eleven.

TABLE 2. Organization of Road Surface Signatures.

Group No.	Surface Code No.	Surface Type
I	1*	asphaltic concrete
	12	old concrete
II	2	new concrete
	8	new concrete
	4	new concrete
	14	new concrete
	19	new concrete
	23	new concrete
	24	new concrete
	29	asphaltic concrete
	30	new concrete
	33	new concrete
	36	old concrete
	39	old concrete
III	3	asphaltic concrete
	25	asphaltic concrete
IV	17	asphaltic concrete
	22*	bituminous asphalt
	26	asphaltic concrete
V	5	bituminous asphalt
	28	bituminous asphalt
	34	bituminous asphalt
	35	bituminous asphalt
	41	bituminous asphalt
VI	6	old concrete
	7	old concrete
	10*	asphaltic concrete
	11	old concrete
	13	old concrete
VII	16	bituminous asphalt
	21	bituminous asphalt
VIII	18	old concrete
	27	new concrete
	31	new concrete
	32	new concrete
	37	old concrete
	38	old concrete
	40*	asphaltic concrete

FIGURE 2. — Relationships between road surface groups.

3. All the main inconsistencies in the grouping (marked with an asterisk) involve the category "asphaltic concrete." Since some difficulty was encountered in trying to classify this surface in the ground survey, problems at a subsequent stage were not altogether unexpected.
4. Despite the difficulties with asphal-

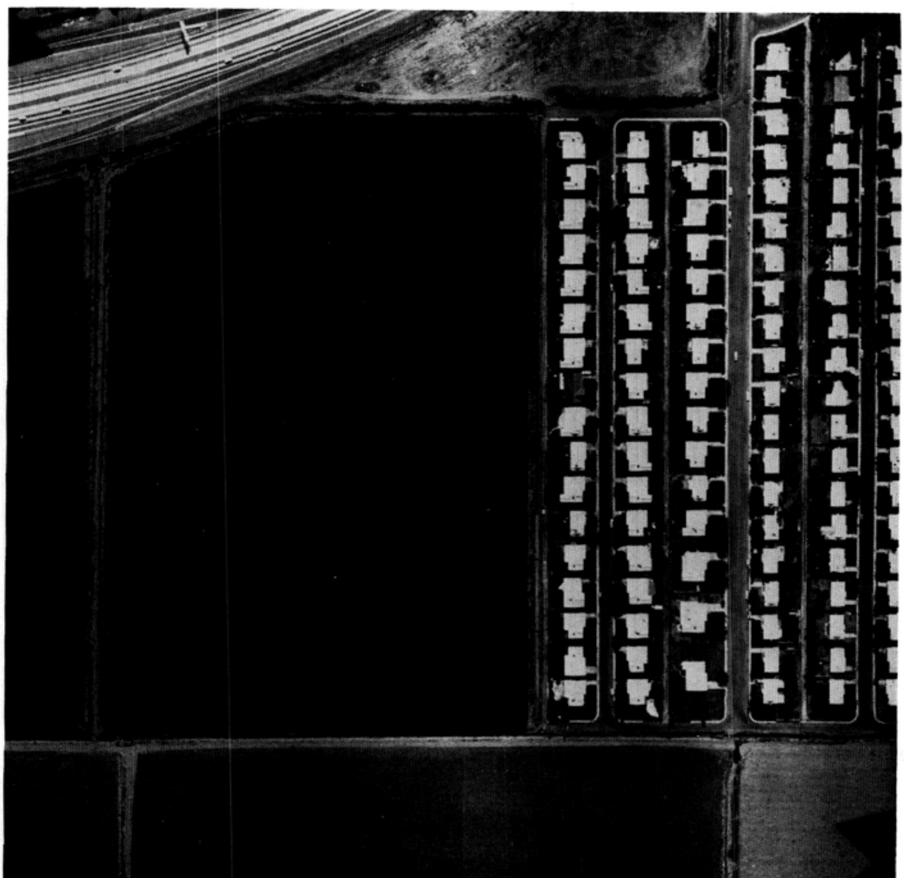

FIGURE 3. — Residential subdivision -0.45 -0.51 mu.

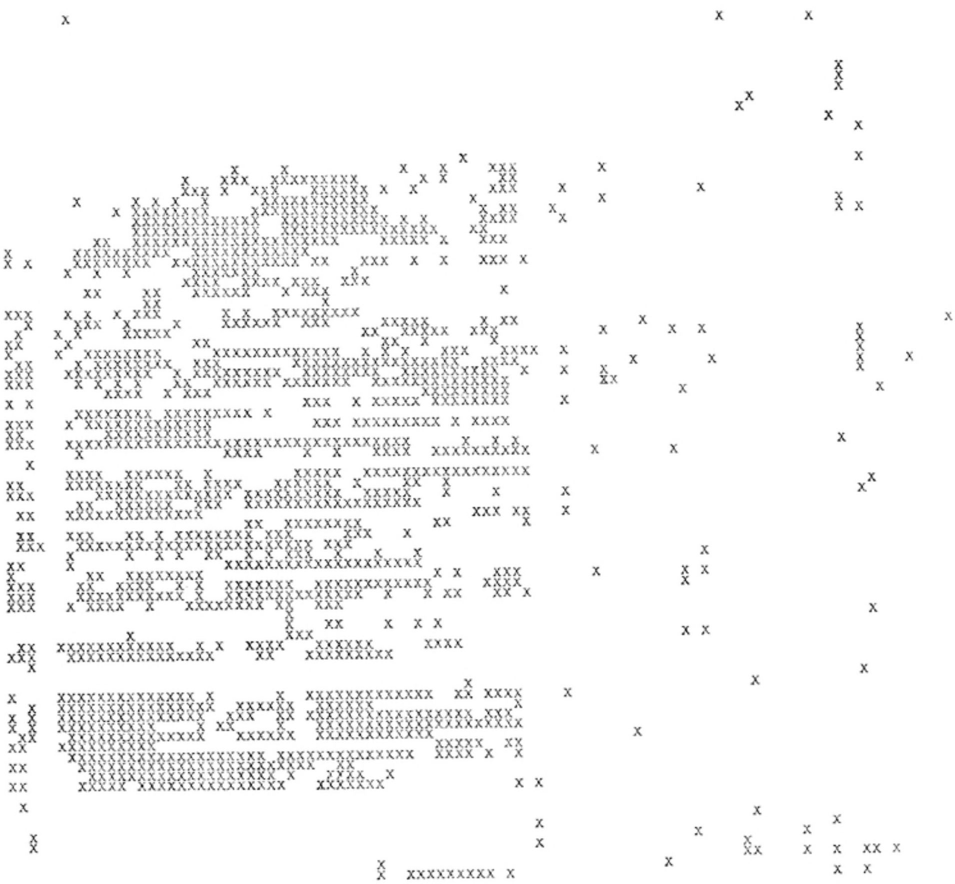

FIGURE 4. — Retrieved pattern of large field.

tic concrete, the results are encouraging. When more data become available, it is hoped to extend this research, applying more rigorous techniques of analysis. With a large controlled sample, it should be possible to determine the parameters of the point distributions in n-space (n being the number of elements in each signature), i.e., the centroid and standard distance of each group in I can be computed. Given this information, it should then be possible to allot a given vector X_i to a similarity set S_j using a Bayesian decision rule, such that an optimal classification of signatures is obtained.

B. Retrieval from Digitized Imagery[6]

Three multiband photographs, each of the same ground area, were selected from a flight over Phoenix, Arizona. One was sensitive to radiation within the range 0.45-0.51 microns, one to radiation within the range 0.52-0.51 microns, and the third within the infrared range 0.80-0.90 microns. These are called images 1, 2, and 3. Image 1 is reproduced as Figure 3.

Each image was divided into 6400 cells (80x80). For each of these cells an average gray scale density was determined, this density being measured along a digital scale from zero to 999. In analyzing these data, a special program was used which provided for the specification of an allowable density range for a variable number of band widths.[7] For example, a rule may be set up such that if the density values for a given element lie between x_1 and x_2 for image 1, between y_1 and y_2 for image 2, and between z_1 and z_2 for image 3, then that element may be classified as a phenomenon P. The elements of the three images are searched sequentially, and each cell that falls within all three limits is "retrieved"—in the cases cited below this takes the form of a locational plot (X) (for an example, see Figure 4).

Figure 4 represents an attempt to retrieve the elements of the large field shown in Figure 3. In order to obtain the density limits for each image, the mean and standard deviation of the density value for all elements of the field were computed for each image. If μ_1 and σ_1 are the mean and standard deviation respectively for the field elements in image 1 then the lower limit x_1 is set to

$$x_1 = \mu_1 - \sigma_1$$

and the upper limit x_2 is set to

$$x_2 = \mu_1 + \sigma_1.$$

y_1, y_2, z_1, and z_2 may be similarly defined.

Elements satisfying all three sets of limits are retrieved and plotted. Of the 2371 cells making up the field, 1164 were retrieved, together with 132 which satisfied the test but were not included within the field.

Figure 1 illustrates a similar experiment undertaken for road surfaces. Once again, the general real world pattern can be identified, but a considerable amount of extraneous data are also recovered.

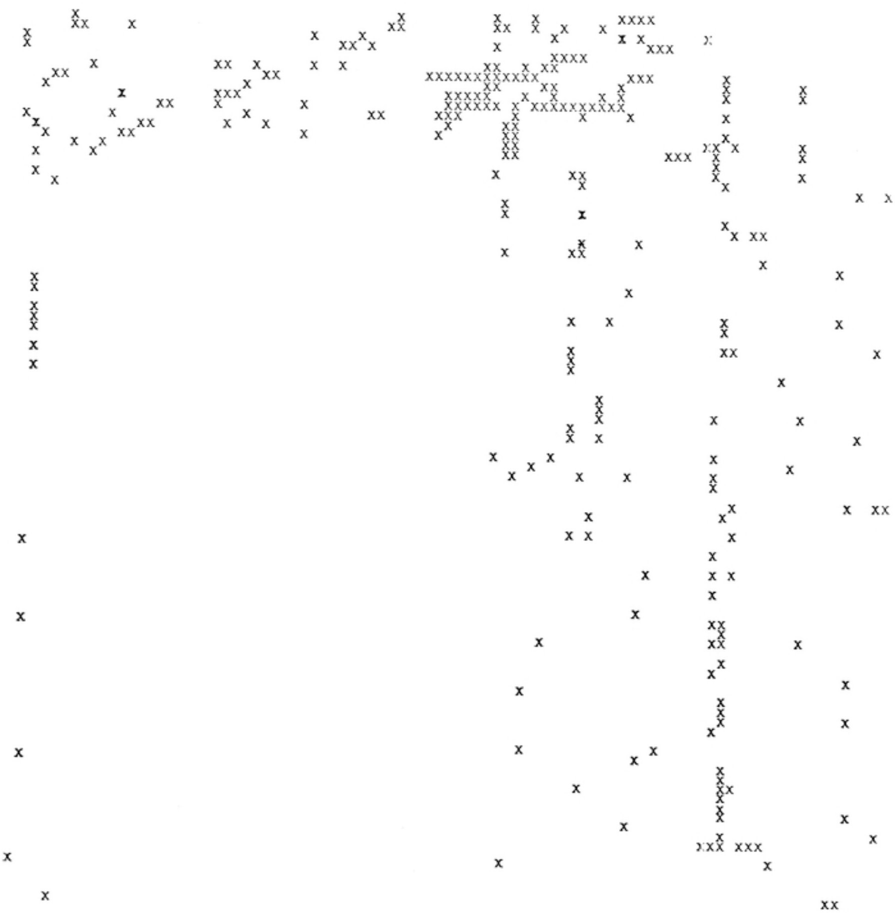

FIGURE 5. — Retrieved pattern of road surface.

The presence of these extraneous data in the two experiments is due to the relatively crude classification algorithms that were used. Surfaces outside the fields such as lawns and parkways were plotted in one case, and non-street surfaces such as concrete paths and patios were plotted in the other. This results from the nature of the recognition technique used, which simply plotted all elements of similar spectral signature in the respective experiments.

The main purpose of this exercise is to illustrate the type of output formats that can be utilized; as more sophisticated pattern recognition procedures are employed, elements satisfying different sets of conditions can be retrieved in the same run, and direct print-outs on that basis of a multiple classification can be achieved.[8]

Conclusion

This paper attempts to illustrate some of the encouraging results that have been obtained in using multispectral photographs to investigate topics of relevance to urban planning and research. It is stressed, however, that multiband imagery is but one type of remote sensing capability. Different sensors perform different functions; as technology advances and provides us with better imagery outside the visible range of the electro-magnetic spectrum (non-classified ultraviolet and thermal infrared imagery is not yet comparable to visible and near infrared photography in resolution capability) our ability to recognize and interpret will rapidly improve. The potential value of remote sensors in the urban area is not in question; the major task is to utilize this potential in the most efficient way.

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