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RECOGNITION OF SETTLEMENT PATTERNS AGAINST A COMPLEX BACKGROUND

by

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FOREWORD

The Dartmouth College Project in Remote Sensing was begun in February 1968 under a grant from the Geographic Applications Program of the Department of Interior's Geological Survey. The initial grant was directed towards a study of certain pre-existing APQ-97 radar imagery flown for the USGS under the auspices of the NASA Manned Spacecraft Center. This initial grant resulted in the report Geographical Evaluation of Radar Imagery of New England, published at Hanover in July 1969.

In the summer of 1968 the Department of Interior Grant was expanded to include multisensor studies; New England was designated a Test Site (No. 176) of the NASA-Manned Spacecraft Center Earth Resources Aircraft Program; and the undersigned was designated Principal Investigator for the Test Site. A NASA CV-240 multisensor aircraft overflew the area in November 1968 (Mission 82) at a planned flight altitude of 10,000 feet. Bad weather prevented flying all of the flight lines or activating all of the sensors. Nevertheless much of the Connecticut Valley, the Dartmouth Second College Grant, and parts of the Boston metropolitan area were recorded in conventional color and color infrared photography, and by a thermal infrared line-scanner. This flight provided the initial imagery for the present study of Recognition of Settlement Patterns against a Complex Background, particularly that for the paper "Line-scan vs Optical Sensors for Discriminating Built-up Areas".

Ten months later, on 14 September 1969, another NASA-MSC flight (Mission 103) was staged over Test Site 176. The aircraft was a C-130B. Sensors included seven cameras with various film and filter combinations optimized for settlement patterns, plus a thermal infrared scanner.

The first published use of imagery from the latter flight is the study by Dr. Lindgren in this volume, on "Dwelling Unit Estimation from Color Infrared Photography". The imagery also has been actively used for studies of pollution and waste disposal, recreational resources, population density, image enhancement, and sensor capability, and has involved a number of people from academic, industrial, and government agencies from New England and beyond.

Finally, on 13 September 1969 (one day prior to the 10,000-foot flight referred to above) an overflight was made in the new NASA RB-57 aircraft, resulting in complete coverage of the Boston urban field from 60,000 feet (Mission 104). This imagery will be utilized, during the summer 1970, to compile an urban land use map of the Boston region, coordinated with the 1970 Census. It is planned to update this map periodically, beginning in 1972, from imagery collected by an Earth Resources Technology Satellite (ERTS) now in the early stages of construction.

Thus the Dartmouth College Project in Remote Sensing includes a combination of research studies funded by NASA Headquarters though the Geographic Applications Program of the Department of Interior, and multi-sensor operational aircraft flights funded by the Earth Resources Aircraft Program of the NASA-Manned Spacecraft Center at Houston. The project is now making a transition from the early, and essential, preoccupation with sensor capabilities and limitations, to emphasis on analysis of the sensor outputs.

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Paper No. 1

DWELLING UNIT ESTIMATION FROM COLOR INFRARED PHOTOGRAPHY

by

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ABSTRACT

The application of aerial photo-interpretation procedures to urban analysis has recently been receiving considerable attention. One application receiving such attention is the estimation of dwelling units in areas of high population density. In this study color infrared photography of metropolitan Boston of a scale 1:20,000 is examined and found to be capable of providing the signatures necessary for making accurate dwelling unit estimates. It is felt that further investigation of color infrared photography may reveal that accurate estimates can be made from scales vastly smaller than the 1:20,000 used here.

DWELLING UNIT ESTIMATION FROM COLOR INFRARED PHOTOGRAPHY

I. INTRODUCTION AND REVIEW

Airborne imagery appears to possess great potential as a tool for urban analysis. At present, however, research in this direction has been limited. One area where research has begun is in the development of methods for estimating the number of dwelling units in areas of high population density. From such estimates a number of additional estimates can be generated including total population and density of population. In this study dwelling unit estimates are made for selected areas of metropolitan Boston using good color infrared (CIR) imagery flown at an altitude of 10,000 feet.[1] The purpose of the study is twofold -- first, to determine whether accurate dwelling unit estimates can be made from medium-scale imagery, in this case 1:20,000, and second, to determine whether in making these estimates CIR imagery offers advantages not offered by panchromatic and natural color imagery.

Several studies have been prepared on dwelling unit estimation, including those of Green[2], Hadfield[3], and Binsell[4]. Green's study of Birmingham, Alabama, was the first of its kind. Using panchromatic stereo pairs of a scale 1:7,500 Green examined seventeen residential subareas,

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[1] Part of Mission 104, NASA-MSC Earth Resources Aircraft Program, 14 September 1969, over Test Site 176 (New England). Ektachrome Aero Infrared Film 8443.

This study was financed by U.S. Geological Survey, Department of Interior Grant No. 14-08-0001-G-8, Robert B. Simpson, Principal Investigator.

[2] Norman E. Green, Aerial Photography in the Analysis of Urban Structure, Ecological and Social (unpublished Ph.D. dissertation, Department of Sociology, University of North Carolina, June 1955).

[3] S.M. Hadfield, Evaluation of Land Use and Dwelling Unit Data Derived from Aerial Photography, Urban Research Section, Chicago Area Transportation Study, Chicago, 1963.

[4] Ronald Binsell, Dwelling Unit Estimation from Aerial Photography, Department of Geography, Northwestern University, June 1967.

recording several categories of housing type. The categories included single-family, double-family, multi-family 3-5, multi-family 6-8, and multi-family 9-11. Identification of housing types was based upon such criteria as form and structure of roof, yards and courts; driveways and entranceways; size, shape and height of structures; and spatial relationships to other buildings. Three major error trends were revealed by this study. First, dwelling units per block were underestimated by 7 percent; second, single-unit detached structures were overestimated by 8 percent; and third, the amount of error increased in areas having a higher prevalence of multi-unit structures. The investigation further revealed that 99.8 percent of residential structures were accounted for by aerial photointerpretation procedures.

S. H. Hadfield's study of Chicago also included a system for estimating dwelling units. The photos in this instance were of a scale 1:4,800; dwellings were classified simply as single family or multiple-family. The estimates made from the photos were checked for accuracy in two ways -- census data and field surveys. The latter were based upon observation of doorbells, mail boxes and utility meters. Hadfield found from his investigation that the original aerial survey showed 10% less dwelling units than the census count. However, when the field survey was used to provide a correction factor the difference between the aerial survey and the census count was reduced to only 0.4 percent. Unfortunately, the nature and development of Hadfield's correction factor were not described in detail.

In a recent study of the Chicago area, Ronald Binsell has experimented with natural color, continuous-strip transparencies at a scale of 1:5,240 for making dwelling unit estimates. Stereo pairs were not employed, and furthermore it was pointed out that no special advantage accrued from the use of color. A variety of residential areas was examined, none of which had been visited by the author prior to the dwelling unit estimation.

Binsell's methodology entailed drawing up a list of keys for estimating the number of dwelling units per residential structure (Annex A) and testing it on two sample blocks. The two blocks were then field checked, revealing a gross overestimation of dwelling units. The keys were adjusted for this factor, and an investigation was conducted on an additional nineteen subareas. A field check of the nineteen subareas revealed the following error trends in the estimates: first, dwelling units were underestimated by 15.7 percent; second, single detached dwellings were overestimated by 4.3 percent; third, the degree of error was found to increase with the prevalence of multi-unit residential structures; and fourth, 99.9 percent of residential structures were identified by aerial imagery. The directions of error, then, were quite consistent with those found by Norman Green.

II. METHODOLOGY

The dwelling unit estimates described in the preceding review were derived from relatively large-scale imagery. Green used the smallest scale at 1:7,500 while Hadfield used the largest at 1:4,800. For this study a scale of 1:20,000 was selected in order to evaluate whether this medium-scale imagery could be used in making dwelling unit estimations. Furthermore, where previous estimates were derived from either panchromatic prints or natural color transparencies, in this study CIR transparencies were employed. It was felt that in high-density areas CIR imagery would allow for easier identification of urban signatures.

The methodology consisted of selecting three test blocks of high-density housing in the metropolitan Boston area. Two of the blocks selected were located in Chelsea, the third in East Boston. The analysis of these blocks was done monoscopically although a stereoscopic analysis could have been conducted. Oblique photos were not available. However, since continuous strip transparencies were being used, a slight oblique view of some blocks was possible. Where such views were possible building heights, that is, the number of stories, could be readily determined. Magnification of the transparencies was done exclusively by hand lenses, the most powerful of which could magnify by a factor of eighteen.

As a starting point the photo-interpretation keys developed by Binsell were systematically applied to the test blocks in order to estimate the number of residential structures and the number of dwelling units. Some of the keys, such as the arrangment of windows, were of little value when working at a scale of 1:20,000. Most, however, were quite applicable although in modified form.

A field check was conducted by the author to determine the accuracy of the estimates and the effectiveness of the keys. Dwelling-unit counts in the field were made on the bases of doorbells, mailboxes and utility meters. Where there remained some question the count was verified by questioning one of the building's occupants. On the basis of this field check the keys were modified. Following is a list of the keys relevant to the dwelling-unit estimates made in this study.

Keys for determining number of dwelling units per structure:

1. Type of roof
2. Relative size of structure
3. Number of stories
4. Division of buildings
5. Availability of parking
6. Amount and quality of vegetation

Keys for distinguishing between residential and non-residential structures:

1. Shape
2. Parking availability
3. Relative location
4. Amount and quality of vegetation

With the completion of the field check, fifteen additional city blocks within metropolitan Boston were selected for examination. Six of the city blocks were located in East Boston, five were located in Chelsea and four were located in Charlestown (Figure 1). Although none of the fifteen blocks had even been visited by the author, some familiarity with the East Boston and Chelsea areas had obviously occurred as a result of the field check of the three test blocks. The four blocks in Charlestown, a section of Boston never visited by the author, were selected in order to test the significance of familiarity in the making of dwelling unit estimates.

The estimates of dwelling units for the fifteen blocks were determined primarily on the basis of four photo keys - roof type, relative size, number of stories, and division of buildings. Roof type, that is, peaked or flat, was usually determined first. Structures with peaked roofs seldom contained more than two dwelling units. The decision was whether the structure was a single-family or two-family unit. Additional factors such

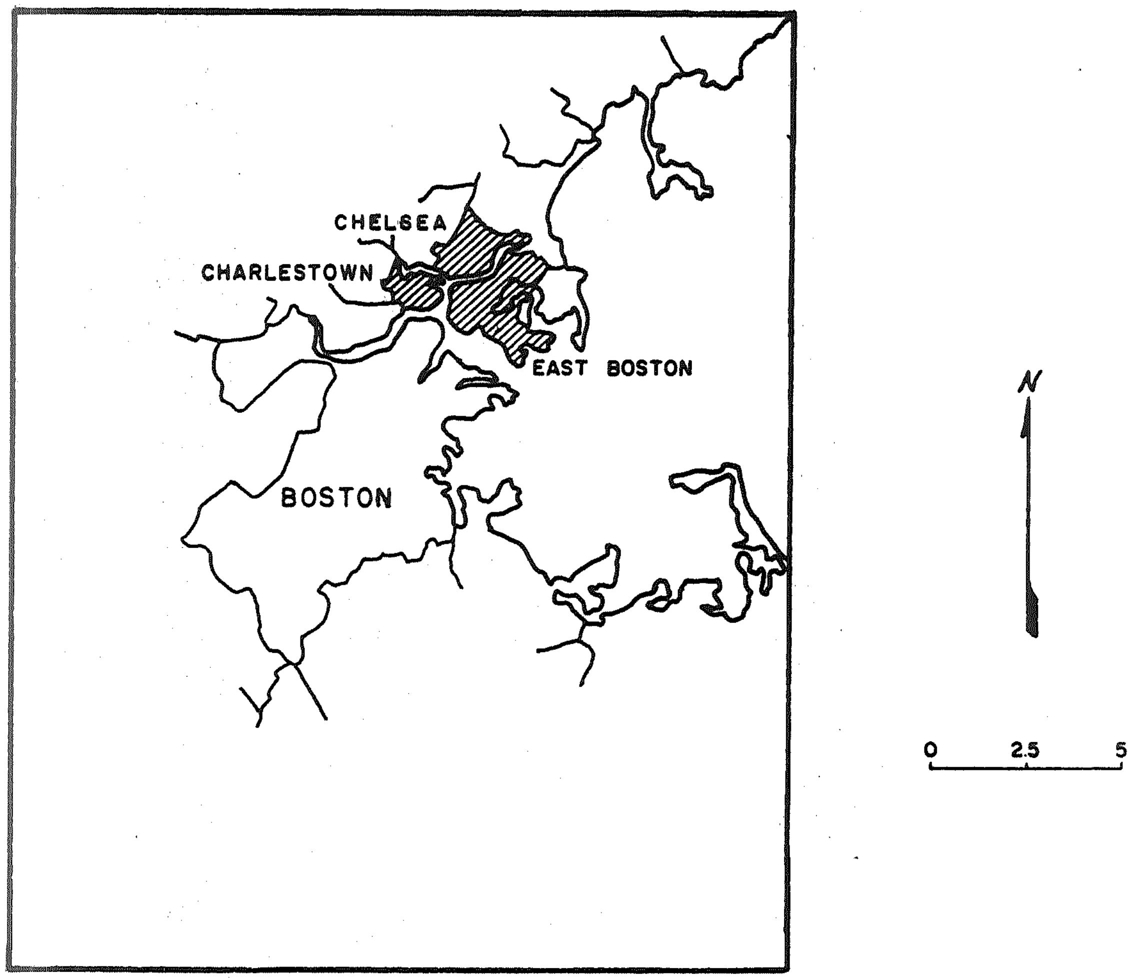

Figure 1. Location of Sample Areas and Blocks Studies. The overall population densities of Chelsea and Boston (of which East Boston and Charlestown are a part) in 1967 were 14,569 and 14,273 per square mile respectively.

as relative size or the presence of a single-car garage were necessarily considered.

Structures with flat roofs usually contained two or more dwelling units. Few structures in the areas investigated contained more than three dwelling units. The number of stories of structures became the best indicator. The determination was made primarily on the basis of shadows, except in those few instances where oblique views were available. To utilize shadows effectively a point of reference such as a garage had to be found. The shadow cast by this structure was then compared to the shadows cast by the residential structures to determine the number of stories. At this point roof divisions such as firewalls were sought to determine whether the building was a single structure of attached.

Although the areas investigated were heavily residential, some non-residential structures were found. For structures such as neighborhood meeting halls or churches, shape such as indicated by shadow was the best key. Parking areas and landscaping were frequently absent from such structures. Other non-residential structures, grocery stores or laundromats could be identified by their corner location or flat roof and one-story height.

III. RESULTS

The results of the investigation of the fifteen blocks appear in Table I. Estimating the number of residential structures per block by aerial imagery of a scale 1:20,000 proved highly successful. Here the CIR film was extremely helpful by providing sharp contract between buildings and vegetation. The figures, therefore, show an overestimation of only one residential structure for the five-block total in Chelsea, and an underestimation of only two residential structures for the six-block total in East Boston and the four-block total in Charlestown. When the figures for the individual blocks are examined the number of errors appears somewhat greater. However, in the area totals the degree of error is less, because underestimations are in some cases offset by overestimations. The total for the three areas shows an underestimation on only three residential structures out of 655. This correct identification of 99.5 percent of the residential structures compares favorable with Green's 99.8 percent and Binsell's 99.9 percent.

TABLE I

ESTIMATED AND ACTUAL NUMBER OF RESIDENCES AND DWELLING UNITS PER BLOCK FOR THREE SAMPLE AREAS

Block Nos.	No. Residences Per Block Photo	No. Residences Per Block Ground	No. DUs Per Block Photo	No. DUs Per Block Ground	No. Residences for which DUs Correctly Estimated
East Boston					
1	52	52	137	138	35
2	47	50	160	151	31
3	41	41	137	147	28
4	46	45	96	87	25
5	52	52	139	137	33
6	48	48	124	127	26
Total	286	288	793	787	178 (61%)
Chelsea					
1	45	43	108	116	22
2	48	48	125	124	29
3	21	21	66	76	17
4	50	51	162	175	26
5	39	39	116	110	32
Total	203	202	577	601	126 (62%)
Charlestown					
1	30	31	43	55	15
2	51	50	76	90	29
3	43	45	106	107	25
4	39	39	95	104	18
Total	163	165	320	356	87 (52%)
Grand Total	652	655	1690	1744	391 (59%)

The areas selected for investigation, as it turned out, were comprised primarily of multi-family structures. There were in fact few single-family detached units. Since previous studies had all shown the degree of error in dwelling unit estimates to increase in areas having a prevalence of multi-unit structures, it is not surprising that the estimates of dwelling units in this study were less accurate than the estimates of residential structures.

The data in Table I show the number of dwelling units in the six-block total for East Boston to have been overestimated by 6, in the five-block total for Chelsea the number was underestimated by 24 and in the four-block total for Charlestown an underestimation of 36 dwelling units occurred. However, when figures for individual blocks are examined the number of errors is greatly increased. Again the degree of error in the totals is reduced by the offsetting of underestimates by overestimates. Significantly this latter situation did not occur in Charlestown, where the number of dwelling units per block was consistently underestimated. This was due in large part to a particular type of roof which was continually misread. Had a test been done in Charlestown this roof type would undoubtedly have been discovered and the resulting analysis would have displayed fewer errors.

The total of the three areas shows an underestimation of 54 dwelling units, or 3.1 percent. The percentage of error compares extremely well with previous studies. Green underestimated his dwelling units by 7 percent, Hadfield by 10 percent and Binsell by 15.7 percent.

One final statistic computed which did not appear in previous studies was the number of dwellings for which dwelling units were correctly estimated (Table I). The largest number of correct estimates was made in the East Boston and Chelsea areas, where percentages were recorded of 61 and 62 respectively. In Charlestown, the one area not visited by the author, only 52 percent of the houses were correctly identified as to exact number of dwelling units.

A chi-square test was applied to the data in Table I as a means of determining the statistical significance of the estimates. In Table II the statistical significance of the estimates of residential structures per

TABLE II

STATISTICAL SIGNIFICANCE OF ESTIMATES FOR NUMBER OF RESIDENTIAL STRUCTURES PER BLOCK

Area	Chi-Square Value	Degrees of Freedom	Critical Value at Rejection Rate of		
			0.10	0.05	0.01
East Boston	.213	5	9.24	11.07	15.09
Chelsea	.109	4	7.78	9.49	13.28
Charlestown	.146	3	6.25	7.81	11.34
Total	.468	14	21.06	23.68	29.14

TABLE III

STATISTICAL SIGNIFICANCE OF ESTIMATES FOR NUMBER OF DWELLING UNITS PER BLOCK

Area	Chi-Square Value	Degrees of Freedom	Critical Value at Rejection Rate of		
			0.10	0.05	0.01
East Boston	2.189	5	9.24	11.07	15.09
Chelsea	3.471	4	7.78	9.49	13.28
Charlestown	6.850	3	6.25	7.81	11.34
Total	12.510	14	21.06	23.68	29.14

block is tested. The chi-square values are presented for the East Boston, Chelsea and Charlestown areas, as well as for the total of the three areas. The estimates are statistically significant if the chi-square value is less than the critical value at selected rejection rates. The critical rejection rates used are 10 percent, 5 percent and one percent. In Table II the chi-square values of the total are all completely significant statistically at the confidence level of 99 percent.

In Table III the statistical significance of the estimates of dwelling units per block is tested. Again the chi-square values are presented for the East Boston, Chelsea and Charlestown areas as well as the total of the three areas. The chi-square values of East Boston, Chelsea and the three-area total are fully significant statistically at the 99 percent confidence level. The chi-square value of Charlestown is significant at the 93 percent confidence level.

IV. CONCLUSION

The major conclusion of this investigation is that accurate dwelling-unit estimates can be made from aerial photographs of a much smaller scale than has been employed in the past. In this case a scale of 1:20,000 made possible estimates which were shown to be statistically significant at the 99 percent confidence level. It should be emphasized that a familiarity with the area under investigation, no matter how slight (a single visit even), will greatly improve the accuracy of the results. If it can be assumed that in most cases an interpreter would have some knowledge of the area in which he is working, then the accuracy of dwelling unit estimates from scales even smaller than 1:20,000 may remain relatively high. Further testing should be carried out using such smaller scales.

Comment should also be made on the value of using color infrared film. It is felt by this investigator that CIR is the most effective film for studying high-density residential areas. Much greater detail can be obtained from its use; the contrast between built-up and nonbuilt-up areas is most obvious. However, even in built-up areas, detail is sharper than with panchromatic or natural color films.

Annex A

PHOTOGRAPHIC INTERPRETATION KEYS DEVELOPED BY BINSELL

Keys used to distinguish between a structure containing a single dwelling unit and one containing two dwelling units:

1. The number of sidewalks leading to the structure
2. The size, shape and height (in stories) of the structure
3. Any indication of a division line in the backyard
4. Number of chimneys
5. Roof shape (flat or peaked).

Keys used to detect the number of dwelling units in multi-unit structures:

1. Roof divisions and number of chimneys
2. Number of sidewalks and sidewalk irregularity
3. Size, shape and height (in stories) of the structure
4. Outside porches and fire escapes (especially at the rear of low quality structures)
5. Arrangement of windows (irregularities indicate unit separation)
6. Roof area and type (flat or peaked)
7. Number of parking spaces.

Keys used to distinguish between residential and nonresidential structures:

1. Lot line
2. Structure, size and shape
3. Associated parking facilities
4. Occurrence or nonoccurrence of front and back yards
5. Contiguous structures.

Paper No. 2

LINE-SCAN VS OPTICAL SENSORS FOR DISCRIMINATION OF BUILT-UP AREAS

by

Robert B. Simpson

Paper No. 2

LINE-SCAN VS OPTICAL SENSORS FOR DISCRIMINATION OF BUILT-UP AREAS

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LINE-SCAN VS OPTICAL SENSORS FOR DISCRIMINATION OF BUILT-UP AREAS

I. INTRODUCTION

A previous study by the present writer determined the capability of radar to permit discrimination of the location, size and shape of built-up areas, utilizing as a format the complex and cluttered landscape patterns of New England.[1] The study revealed the capability of a statistically determined "average competent interpreter" to discriminate the interfaces between built-up and nonbuilt-up areas. Imagery used was of "fair" quality, recorded in July 1966 by a Westinghouse APQ-97, K-band, dual-polarized radar.

Thermal infrared (TIR) and optical (photographic) imagery of many of the same areas was obtained in November 1968 by an overflight of the NASA-MSC Convair 240, at an altitude of 8,500 - 10,000 feet. Scanner was a Reconofax IV (uncalibrated) imaging in the 8-14 micron band. Time of day was between 10AM and 2PM (local). Quality of the imagery was good.

Compatible camera coverage was obtained, simultaneously, on Ektachrome 8442 film, 9x9-inch format. Color infrared (CIR; Ektachrome Infrared Aero Film 8443) imagery was attempted, but was marginal in quality due to unfavorable weather conditions.

For further detail on the sensors, missions and imagery see Annex A. As a result of these two missions it became possible to compare the relative usefulness of the two kinds of line-scanned imagery, TIR and radar with photography as well as with ground truth for the discrimination of built-up areas. These comparisons are the subject of this report.

Although Alexander and colleagues (see Bibliography, Annex C), highlighted the importance of such research in a keynote presentation at the Fifth Symposium of Remote Sensing in April 1968 little has yet been done to define the capability of sensors to reveal the location, size and shape of built-up areas. Sabol used radar imagery for built-up area discrimination

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[1] Simpson, R.B., Geographic Evaluation of Radar Imagery of New England, Interagency Report NASA-163 (1969)

at about the same time the present writer published his detailed consideration of this subject in July 1969. At the Sixth Symposium on Remote Sensing in October 1969 the use of space photography, high-altitude photography, and low resolution imagery in general were discussed in terms of urban applications by Weller, Holz and colleagues, and Marble, respectively (see Annex C). However, we are moving into a period of intensive study of rural-urban pattern interfaces with only limited knowledge of the effectiveness of our multi-sensor tools.

II. PROCEDURE

1. Selection of sample areas

First step in the present evaluation was to identify those areas in New England which had been covered both by the radar flight of July 1966 and the optical-TIR flight of November 1968, both of which were single-swath efforts. Such areas were found in the Boston metropolitan area and along parts of the Connecticut Valley. They afforded good variety in settlement pattern densities, ranging from the high densities of the core of Boston out across its urban sprawl into the hinterlands and in rural northwestern New England from a rural manufacturing town of 3,000 down to the open patterns of individual scattered farmsteads.

Six sample areas were selected (Figure 1) to represent the spectrum of population density. No representative of the highest density, central city, area was chosen, since in such an area no significant built-up, nonbuilt-up interfaces are present. In fact, the density-descriptive adjectives assigned to the sample areas in the following paragraphs are designed to fit the needs of this study only. (In global core-city terms, for example, a density of 6,500 persons per square mile would be "low" rather than "high-medium").

Sample 1: A high-medium density (6,500 per sq. mi.) area in mid-city; mostly multifamily residential structures but also a high percentage of mixed wholesale, retail and service activities plus a few large factories. Breaks in the built-up pattern are presented by a stream and by scattered areas of poorly drained ground, rock outcrops, cemeteries and the like. Part of the metropolitan Boston Town of Waltham. (Figure 6)

Sample 2: A low-medium density (4,000 per sq. mi.) residential area; largely single-family dwellings but closely spaced -- an older, middle-class residential area. Typified by large areas of spreading individual trees, and broken by massive wooded areas associated with ridges and ponds, the latter serving as reservoirs for the city water supply. Part of a residential suburb lying mostly in the Town of Winchester but partly in the Town of Medford. (Figures 2 and 3)

Sample 3: A very low density (700 per sq. mi.), very high income, modern residential area on the outskirts of Boston, characterized by a completely rural, rolling, wooded ambient, broken by openings of half-acre or so apiece for the individual house-lawn or house-lawn-swimming pool combinations. In the Towns of Weston and Wellesley, Massachusetts, on the west side of metropolitan Boston.

Sample 4: An entire large rural town of 3,000 people, with density averaging 1,500 per square mile, plus the surrounding rural fringe. The town is on the Connecticut River, includes interstate highway and rail transportation, two factories (Cone automatic machines and Goodyear heels), and a state prison. The incorporated village of Windsor, Vermont, which dates from Colonial times. (Figures 4 and 5)

Sample 5: Although essentially made up of agricultural Connecticut Valley terrace terrain, this sample is conspicuously marked by two linear, along-road hamlets, on opposite sides of a bridge across the river. Overall population density, 300 per sq. mi. The hamlets are Orford, New Hampshire and Fairlee, Vermont.

Sample 6: Truly rural terrain, occupied only be scattered farmsteads except for a very small agglomeration and two trailer parks at the eastern end of the sample. Overall density 60 per square mile. Part of the Town (ship) of Ascutney, Vermont.

2. <u>Size and shape of the sample areas and their images</u>.

Each sample area represents a patch of ground very roughly 1.5 miles square, the contact scale of the optical imagery having been reduced to 1/4x, and the TIR and radar enlarged to 2x and 3x respectively, to attain rough congruence. However, scale distortions due to (1) the geometry inherent in the sensors, (2) variations in flight altitude due to cloud cover, and (3) variations in attitude of the aircraft are considerable. Thus the characteristic shapes of the sample images for each sensor depart considerably from the square, especially in the case of TIR. Projecting each of the sample chips onto accurately scaled bases would reveal additional individual distortions. Essentail technical detail as to distortion, scales, sensors and operational parameters can be found in Annex A.

3. <u>Authentication of interpreter competence and ground truth</u>.

An opportunity to partially validate the degree of competence of the interpreters[1] in this study is afforded by "bridging" back to an earlier study by the present writer (Annex C). In the previous study, the 25 most competent radar interpreters available nationally were asked to interpret certain radar imagery, including (but on a much smaller scale) the present samples. The "typical highly competent interpreter" (that is the median scorer of that group) scored 81.3 at that time over the area covered by the present samples. The best single scores attained by anyone for these samples at that time averaged 89.6 Our interpreter for radar and TIR in the present study (MacNeill) scored 85.1 on the same basis.

Ground truth for the six sample areas was collected in the field on three separate occasions by this writer, by the interpreters involved (after completing the interpretation), and by groups of students (working from 12x enlargements of the sample chips and from topographic maps).

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[1] Arthur E. MacNeill, Jr., Dartmouth '68, radar and TIR
Mark Hallenbeck, Dartmouth '70, photography

4. <u>Scoring the success of the sensors.</u>

Using paper print versions of each of the six sample areas as imaged by each of the three sensors, a total of 18 different acetate overlays of the location, size and shape of the built-up areas was prepared. A copy of the instructions to the radar-TIR interpreter is attached hereto as Annex B. Similar instructions were given to the optical interpreter.

The 18 built-up patterns drawn by the interpreters were scored against a cellular ground truth grid, the making of which proved to be laborious. Eighteen different ground truth overlays had to be compiled -- one for each sensor and each sample, because of the different distortions in each image. (A side experiment showed that individual differences of opinion in converting a linear to a cellular ground truth map prior to scoring, produced only a $\pm$ 5% deviation in the resultant scores).

Scoring of the degree of accuracy in discriminating built-up from non-built-up areas was done on a conservative basis:

$$\text{Score} = \frac{\text{hits} - (\text{misses} + \text{false alarms})}{\text{total } \underline{\underline{\text{built-up}}} \text{ cells}}$$

Notice that the score does not depend on the total number of cells but only on the total number of built-up cells. Since it is theoretically possible to run up almost as many false alarms as there are grid cells in the sample, it is also possible to total more errors than hits, and thus to earn a <u>negative</u> score. (This was actually done in the case of radar against the most rural sample area, as will be shown later). Although the scores look at first glance like percentages, the fact that negatives scores are possible rules out this convenience.

Having scored each of the three sensors against each of the six diverse sample areas (Table I) analysis of the relative capabilities of the sensors could proceed.

Table I

RADAR - TIR - OPTICAL SCORE SHEET

$$\text{Score} = \frac{\text{hits} - (\text{misses} + \text{false alarms})}{\text{total built-up cells}}$$

Urban Densities

	High-Medium (I) (Waltham)	Low-Medium (II) (Winch.)	V.Low (III) (Weston)	Rural Town (IV) (Windsor)	Rural Hamlets (V) (Orford)	Rural Farmsteads (VI) (Ascut.)	AVERAGE
TIR	80.6	90.7	87.8	84.1	70.8	43.6	76.4
Radar	84.2	78.1	50.0	59.0	29.8	neg. (1)	60.2 -(2)
Optical	96.0	98.3	91.8	96.5	77.9	86.9	91.2
	86.9	89.0	79.9	79.9	59.5	(neg.) 3	75.9 -

(1) actually $\frac{\text{minus } 28}{35}$

(2) excluding the Rural Farmsteads sample from the averaging

(3) the average for TIR and optical alone is 65.3

III. FINDINGS

Table II amplifies on Table I and categorizes the relative utility of the sensors. The reader can glean a variety of conclusions from Table II, and from the Illustrations (Annex D) but following are a few highlights:

1. Each sensor falls into a separate effectiveness category.

The scoring system provided a good range of scores, from a high of 98 to a low below zero. It also produced sharp breakpoints in scores, which make effective dividers between categories. Cameras in this type of mission fit the "use with confidence" category, overall. Daytime TIR rates one step lower, as "acceptable" overall, and radar must be regarded as only "marginally acceptable" in the role of interface definer, at comparable scales.

2. The scanning sensors are at their best against urban environments.

Since scanning type sensors have been used largely against rural-type targets, such as landforms, vegetation, and agriculture in the past, one might expect that they do less well against urban-type targets. Such is not the case. Both TIR and radar score higher against the urban and suburban patterns of Megalopolis than they do against the smaller, scattered-building interfaces of rural New England. Reason is the tendency towards extensive, repetitive geometric shapes in the man-made street and structure patterns of the city, in contrast to the highly irregular and fragmentary shapes of the built-up units imbedded in a haphazard clutter in most rural landscapes. Line-scanners should not be thought of as primarily rural sensors.

3. There are almost no target types for which one would prefer radar or TIR to photography.

If one has complete freedom of choice, there are essentially no target types within the scope of this study for which he would prefer radar to daytime TIR, or daytime TIR to optical cameras. This finding is implicit in Table II.[1]

However, radar might still be preferred under those now widely recognized circumstances where the operational situation dictates sensing when cloudy or extremely hazy weather precludes photography, or where a preliminary planning or navigational aid is required in connection with a later high-order survey. Radar might be preferred if fewer flight lines, and/or decreased photo lab time, were overriding. Similarly, TIR might be preferred if a small degradation in resolution is acceptable as a trade -off for a night-time operation, fewer flight lines, decreased photo lab time, or a ready capability for digital manipulation.

4. Each of the three sensors optimizes built-up vs. nonbuilt-up interfaces differently.

Even with a purely descriptive, non-theoretical, approach it is possible to generalize on some of the types of signatures associated with built-up area interfaces. For examples see Figures 2 through 6.

a. Radar: Built-up area interfaces are relatively easy to recognize, of course, if an area of "blooming" such as from an industrial or commercial development, abuts anarea of low returns. Here the contrast is one of tone more than texture. Next most favorable situation depends more on texture. It exists where an older residential area creates a stippled "salt-with-pepper" image (Figures 2a, 4a and 6b) due to an intimate intermixture of individual tree crowns, rooftops and patches of street and lawn. This salt-with-pepper texture contrasts with most other patterns contiguous to it. Although individual streets occasionally show up on radar, neither street counts nor house counts are feasible on these returns.

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[1] The table does include one case where radar scores higher than TIR. This is the "urban high-medium" density category of Waltham, Massachusetts, where radar scored 84 to TIR's 81. Here is an area of unusually strong differentiation in culture patterns, with large, relatively densely populated residential areas, a major manufacturing complex, a large retail shopping center, a cemetery, truck gardens, institutional terrain, and wet marshy areas. It is an area of unusually sharp contrasts in emissivity and reflectively for TIR, but even sharper contrasts in radar reflectance. For the TIR and radar images see Figure 6.

b. TIR: On daytime TIR the best built-up area returns are associated with uniform residential areas, where rows of houses produce parallel lines of "corn-on-the-cob" or "rows-of-teeth" high-energy returns (Figures 2b, 4b and 6a). Street counts are quite dependable although individual house counts are seldom practical. The presence of trees, especially individual trees, weakens the patterns, but not nearly so drastically as they do in optical photography. Interfaces can be accurately delineated where "corn-on-the-cob" patterns abut almost any other texture.

c. Photography: In conventional aerial photography maximum returns from a built-up area are associated generally with a solid residential pack of post-1950, and preferably post-1960, housing. Modern suburban roofs are mostly light-shingled, and in new housing developments tree crowns generally are small and low in height (Figures 2c, 3 and 4c). Accurate house counts as well as street counts generally are practical, and interfaces with nonbuilt-up land can be rapidly and accurately drawn.

Table II

OVERALL UTILITY OF SENSORS (AT A COMMON SCALE)

FOR DISCRIMINATING LOCATION, SIZE AND SHAPE OF BUILT-UP AREAS

Urban population densities: hm= high medium lm= low medium vl=very low

	Use with Confidence (90-100)	Acceptable (70-89)	Marginally Acceptable (50-69)	Apt to be Misleading (below 50)
OPTICAL	OVERALL (92) Urban lm (98) (II) (Winch.) Rural town (97) (IV) (Windsor) Urban hm (96) (I) (Waltham) Urban vl (92) (III) (Weston)	Rural farmsteads (87) (VI) (Ascut.) Rural hamlets (78) (V) (Orford)		
TIR	Urban lm (91) (II) (Winch.)	OVERALL (77) Urban vl. (88) (III) (Weston) Rural town (84) (IV) (Windsor) Urban hm (81) (I) (Waltham) Rural hamlets (71) (V) (Orford)		Rural farmsteads (44) (VI) (Ascut.)
RADAR		Urban hm (84) (I) (Waltham) Urban lm (78) (II) (Winch.)	OVERALL $61^{-(1)}$ Rural town (59) (IV) (Windsor) Urban vl (50) (III) (Weston)	Rural hamlets (30) (V) (Orford) Rural farmsteads (neg.) (VI) (Ascut.)

(1) less Rural farmsteads (neg.)

IV. SUMMARY AND CONCLUSIONS

Assuming daytime flights at medium altitude in good weather, the relative ability of the common imaging sensors to discriminate built-up from nonbuilt-up areas in a humid mid-latitude environment is as follows:

camera -- use with confidence
TIR - acceptable
radar -- marginally acceptable

Only under special operating conditions related to weather, cost and the like would one select radar or TIR in preference to photography.

Contrary to what might be expected,the scanning sensors are more effective against settlement patterns in built-up areas than in undeveloped ones.

Cameras record built-up areas best in starkly new, single-family residential areas; TIR is less dependent on newness or nakedness; and radar does best where a varied intermixture of rooftops and tree crowns prevails.

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Annex A.

TECHNICAL DATA

ON SENSORS, MISSIONS, IMAGERY AND SAMPLE CHIPS

RADAR

APQ-97, K-band, multiple-polarized. HH mode, HV available for reference.

Mission: Flight No. 125, July 1966

Scale of Original Imagery: 1:186,000 average (subject to 8% variation)

Sample chips: approximately 3x enlargements
size 1.4 inches x 1.4 inches, or approximately
1.6 miles x 1.6 miles, + 13%
scale 1:70,500 transverse and 1:73,500 parallel
to flight line, ± 8%

THERMAL INFRARED

Reconofax IV, 8 - 14 microns, automatic gain setting, uncalibrated,

Mission: NASA ERAP 82, November 1968, 10,000' alt. (over 3 Boston samples)
and 8,500' (over Connecticut Valley samples).
Convair CV-240.
time 11 AM - 12 noon local

Scale of original imagery: 1:120,000 average (subject to 28%
variation due to (1) x-y distortion,
and (2) difference in flight altitude.

Sample chips: approximately 2x enlargements
size 1.2 inches transverse x 1.7 inches parallel
to flight line, or approximately 1.3 miles transverse
x 1.4 miles parallel to flight line, ± 15%
scale 1:48,000 transverse and 1:72,600 parallel to flight
line, ± 13%

OPTICAL

RC-8, 6" focal length, Ektachrome 8442 film with haze-and antivignetting filters (Ektachrome Infrared Aero, 8443, also available, taken thru 500 nm filter in 6" focal length, RC-8 camera, but under-exposed).

Mission: same as for TIR above

Scale of original imagery: 1:18,500 average (subject to 8% variation
due to altitude)

Sample chips: approximately 1/4 x reductions
size 1.6 inches transverse x 1.3 inches parallel
to flight line, or approximately 1.8 miles transverse
x 1.3 miles parallel, ± 20%
scale 1:68,300, ± 9%

Annex B

INSTRUCTIONS FOR

RADAR - TIR COMPARISON TEST

Materials:

12 enlarged paper prints (six radar and six TIR) of the same six areas in New England will be furnished. Supporting positive transparencies at contact scale also will be available.

Size of area:

approximately 2 miles square.

Scale of prints:

roughly 1" equals 1.5 miles (plus or minus 50%).

Included are areas of CBS-industrial-commercial usage, high density urban residential, low density urban residential, low density rural, intra-urban wooded parkland, and rural countryside.

Radar images:

July 1966, K-Band, HH

TIR images:

November 1968. 10:00 A.M. - 12 noon. 10,000 feet.

Reconofax IV. 8-14 microns.

Problem:

1. Using overlay materials, draw a pencil line to separate built-up from nonbuilt-up areas. Minimum size of built-up areas delineated depends on scale and resolution of the imagery. Be as detailed as practicable.

   (Obviously, in a high density city residential area, each dwelling cannot be shown separately. However, exclude parks and other non-built-up sites. In the country if you can discriminate an individual dwelling or group of farm buildings, draw an individual circle around them. If there are six farms scattered at "open" intervals along a rural road, show all six separately. If they are too close together to easily and clearly separate, draw a line around the group).

2. Do outline all easily distinguishable water bodies, to aid in orientation. Color them blue. (You will not be scored on these).

3. Do show a few key linear features such as roads, railroads and power lines. Do not show many, nor attempt to differentiate them. (You will not be scored on these).

Product:

Turn in 12 overlays at the scale of paper prints furnished (radar is 3x,TIR is 2x), with water bodies in blue and a few linear features sketched in, plus lines separating built-up from nonbuilt-up areas.

Aids permitted:

You are free to use transparencies, light tables, magnification and other routine aids.

Time:

No time limit.

Scoring:

YOU WILL be scored against a cellular, ground-truth-gridded map. You will win points for hits, and LOSE POINTS EQUALLY FOR BOTH MISSES AND FALSE ALARMS.

Annex C

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Annex D

ILLUSTRATIONS

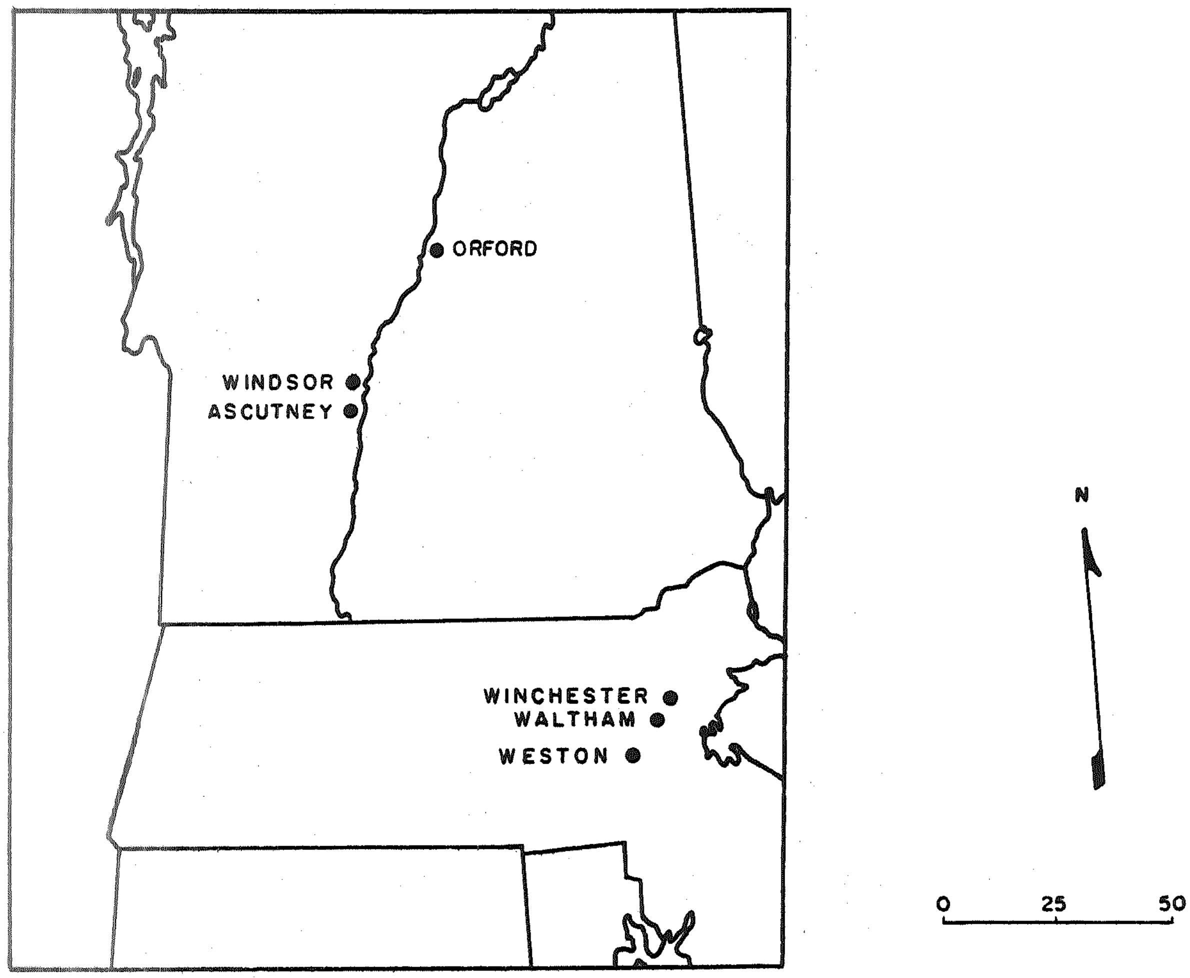
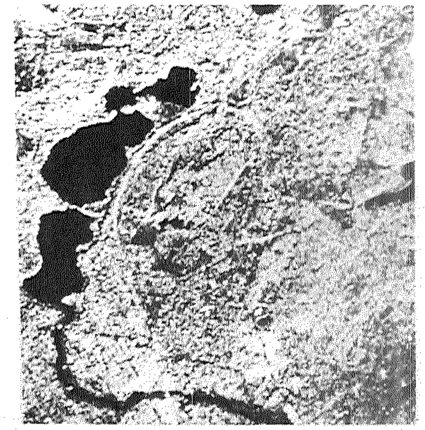
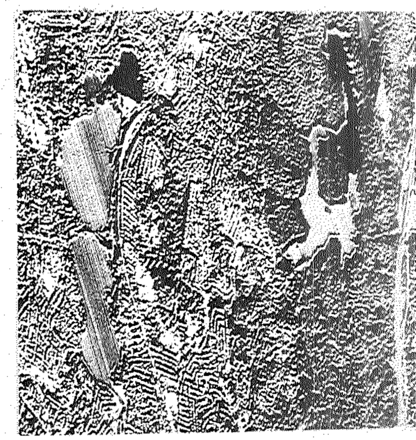


Figure 1. Location of the Sample Areas.

a. Radar.
(Interpreter's score 78).
Stippled "salt-with-pepper" patterns well shown in lower left corner. Neither street counts nor house counts generally practical.



b. TIR.
(Interpreter's score 91).
Linear "corn-on-cob" patterns widespread. Street counts practical, house counts not. Note temperature differences in the lakes.



c. Optical.
(Interpreter's score 98).
Both street and house counts practical. (From an Ektachrome negative)

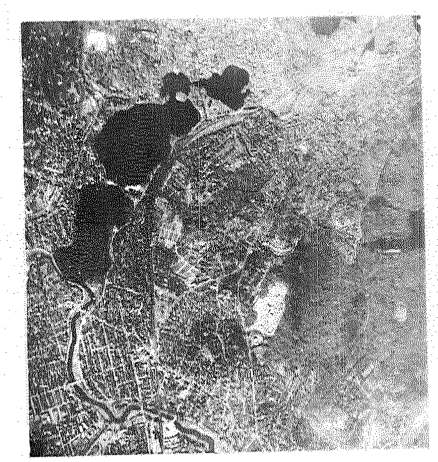


Figure 2. Multisensor Images, Low-Medium Density Area (Winchester, Massachusetts).

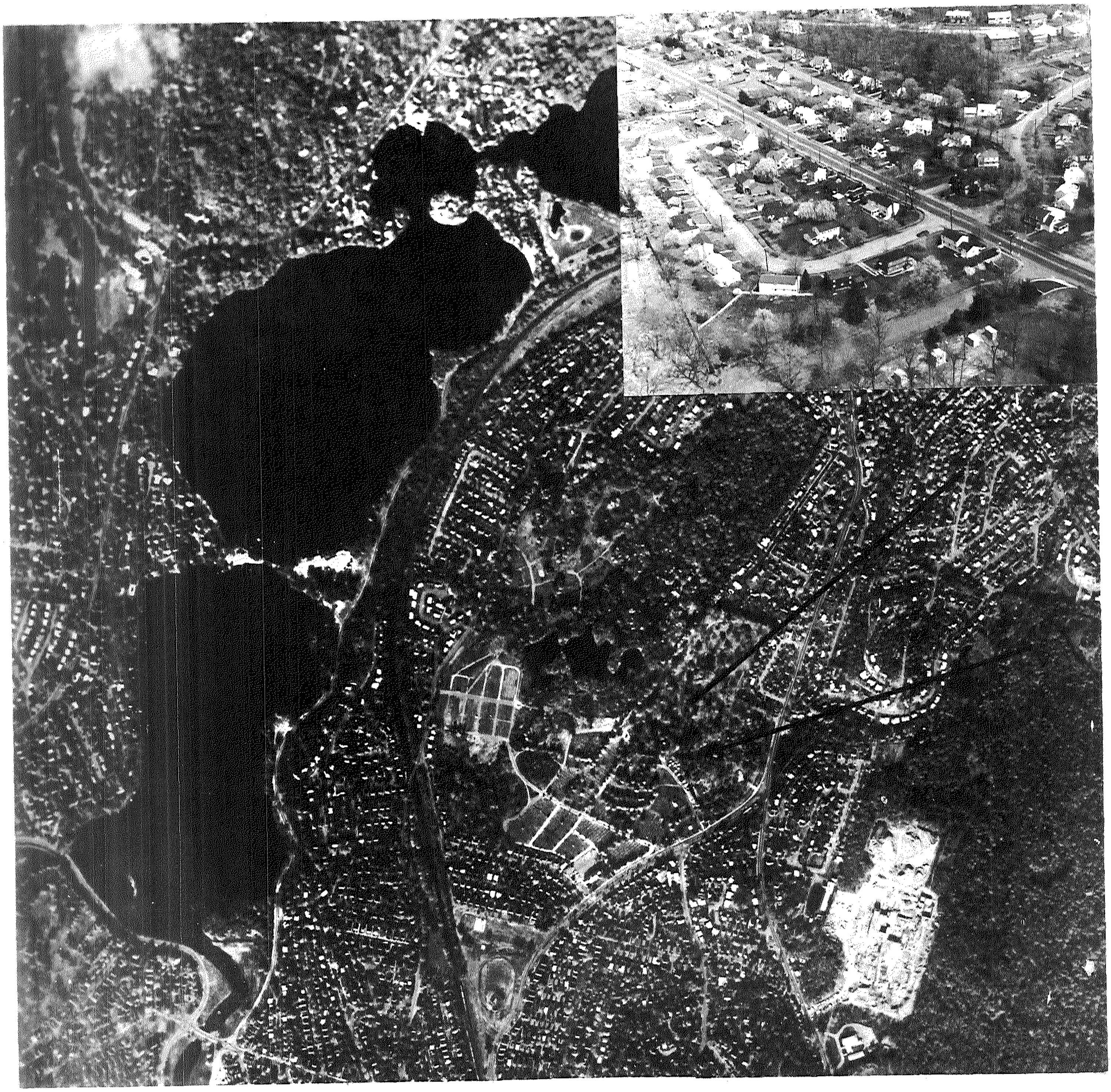
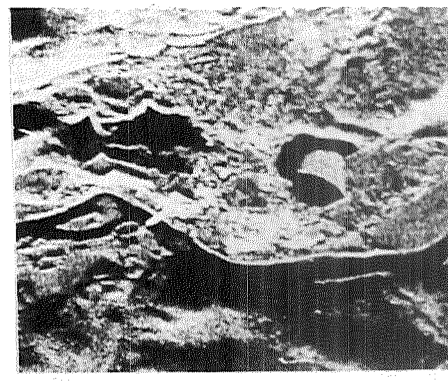


Figure 3. Winchester, Massachusetts Sample: A Low-Medium Density Built-Up Area.
The inset shows ground truth for the area marked, including interfaces between built-up and nonbuilt-up, roof material effects, and tree cover influence (vertical photo taken in early autumn, oblique in early spring).

a. Radar.
(Interpreter's score 59).
Blooming, rather than stippled patterns, characterizes this built-up area.
Neither street nor house counts practical.



b. TIR.
(Interpreter's score 84).
Edges of the built-up area show clearly, although normal linear patterns somewhat fragmented.
Few street counts and no house counts practical. The dark rural areas are forested.

c. Optical.
(Interpreter's score 97).
Both street and house counts practical.
(From an Ektachrome Aero Infrared negative).

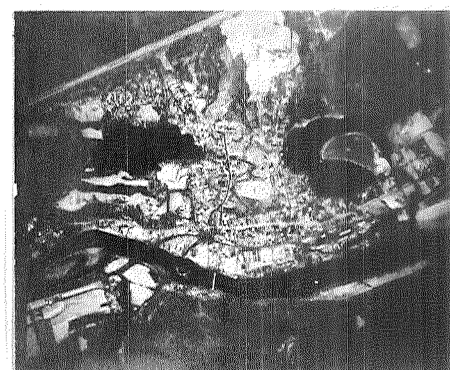


Figure 4. Multisensor Images, Rural-Town Built-Up Area (Windsor, Vermont).

(Anscochrome negative, J. Sommer)

Figure 5. Windsor, Vermont, Sample Area.
Connecticut River in the foreground. The prominent, light-toned, multiple-arch vaulted roof near the river on the left is part of the Goodyear heel plant.

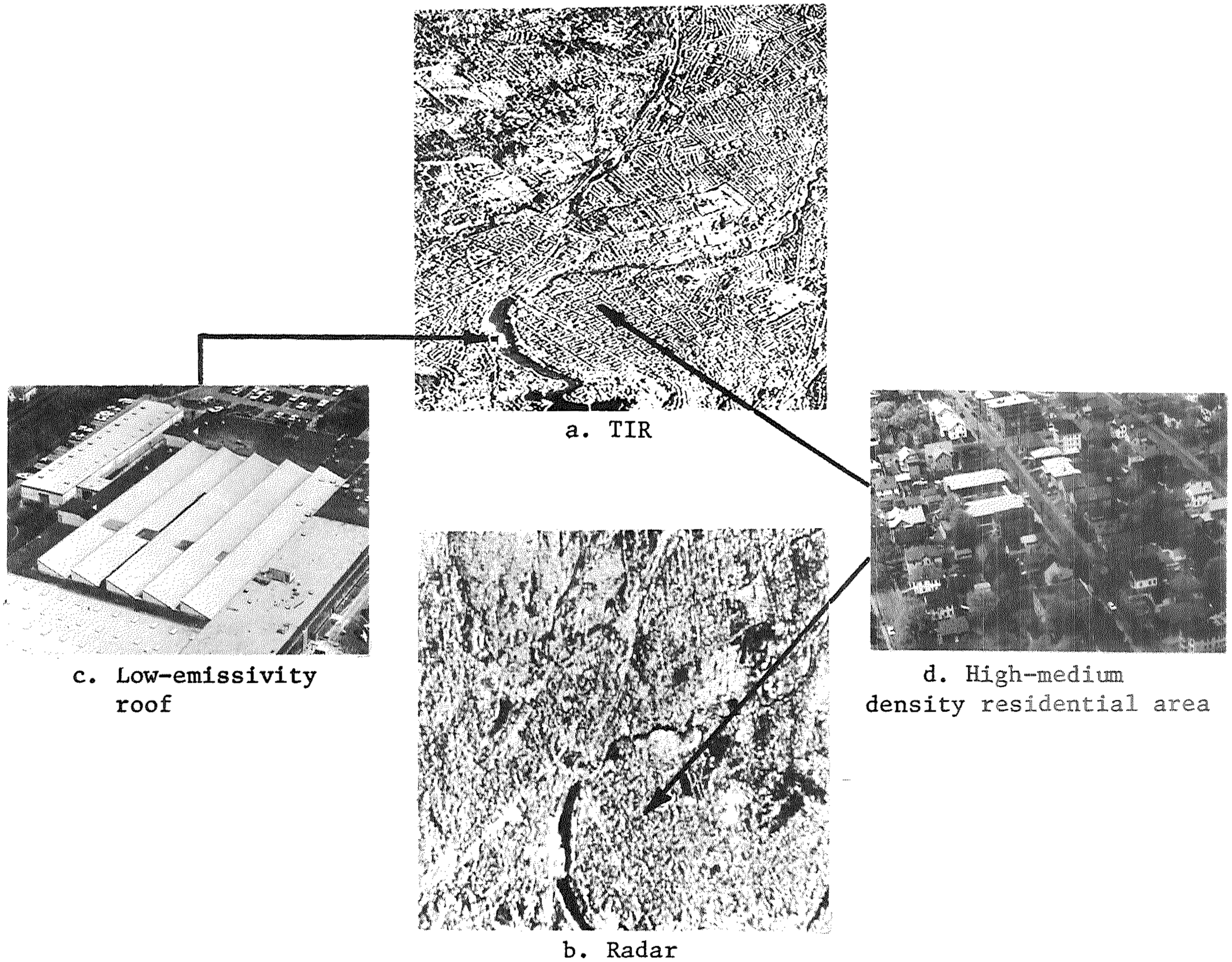


Figure 6. High-Medium Density Built-Up Area, as shown by Line-Scanners. The Waltham, Massachusetts sample. This general area averages 6,500 people per square mile.
The cold spot on the TIR image (8-14 microns) owes its origin to the sawtooth roof, which has been covered completely with heavy roofing fabric and doused with aluminum paint.

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16. Abstracts The application of aerial photo-interpretation to estimation of dwelling units in areas of high population density is examined. In this study, color infrared photography of metropolitan Boston at a scale of 1:20,000 is found capable of providing the signatures necessary for making accurate dwelling unit estimates.

Repetitive multisensor overflights of New England have made it possible to compare directly the utility of radar and thermal line-scanners with optical systems for discrimination of built-up areas. Six sample areas were selected, three from Boston metropolitan area and three from the Connecticut Valley. It was determined that the optical system could be used with confidence, the thermal infrared was acceptable, and the radar was marginally acceptable; scanning sensors are at their best depicting urban patterns, not rural ones; and there are essentially no built-up area targets against which line-scan systems perform better than optical ones.

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