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REMOTE SENSOR IMAGERY IN URBAN RESEARCH: SOME POTENTIALITIES AND PROBLEMS

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ABSTRACT

In evaluating the potential of a new technique of urban data collection attention must be paid to existing needs. The first part of the paper considers a number of requirements that should be satisfied by urban data if a sound base for planning and research is to be provided. The second part describes the properties of remote sensors and discusses the extent to which (1) they generate data which are compatible with the specified requirements, and (2) they might help to reduce current urban data deficiencies. Finally, the potentialities of three sensor types (the multiband camera, thermal infrared sensors, and imaging radars) in specific areas of urban research are assessed.

REMOTE SENSOR IMAGERY IN URBAN RESEARCH: SOME POTENTIALITIES AND PROBLEMS

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Collection and processing of data have posed problems for many scientists concerned with the study of urban phenomena. Much recent effort has been devoted to redefining the information needs of planners and policy-makers, yet relatively little progress has been made in developing methods of satisfying these needs. This paper is concerned with the potential contribution of remote sensors in data collection. It is suggested that their use will help to overcome some of the existing urban data problems.

The study comprises three parts. In the first, attention is focussed on a number of data requirements. Certain inadequacies with respect to these requirements are identified in existing urban data sets. The second part provides a statement of the properties of remote sensors and discusses their role in data collection. Suggestions are made as to the way in which the use of remote sensors might reduce current data deficiencies. The final section assesses potentialities of various remote sensors in specific areas of urban research.

I - URBAN DATA REQUIREMENTS

Recent studies have proposed a number of requirements that should be satisfied by urban data, if a sound base for planning and research is to be provided.[1] The following are considered to be of particular relevance to a discussion of the utility of remote sensors in urban areas.

Timeliness - Timeliness refers to the temporal relationship between user demands and output of a data collection system. Two aspects are relevant. The first is the frequency with which complete data sets may be obtained. To understand the rapid changes experienced by many elements of the urban scene, frequent observations are required. In many cases, too coarse a time frame imposes severe constraints on the ability to monitor change; much of the material contained in the decennial Census falls into this category. On the other hand, special surveys, which are usually designed to generate data on a 'one shot' basis, are expensive and are often difficult to replicate.

The second aspect of timeliness is the temporal correlation of the observations forming one data set. The closeness of this correlation is important to the planning of transportation facilities. For example, in attempting to evaluate the efficiency of existing networks it is frequently necessary to obtain traffic-flow data for the brief, yet critical, rush-hour period. (Ref. 22) Other data sets have different temporal requirements; the Census of Population attempts to collect data relevant to household characteristics for a single day[2], and the time constraint for land use surveys is still less restrictive.

Flexibility - Flexibility refers to the capacity to satisfy the needs of a variety of users. This is particularly relevant to the consideration of the level of aggregation required for a given data set. Clawson stresses that basic recording should possess the maximum of detail and the minimum of *a priori* classification. (Ref. 3) The smallest possible parcel of land (the individual lot) should be used as the elemental recording unit. Only under these conditions can data be sufficiently flexible to cater to such diverse needs as those of school district planning, local government zoning, and evaluation of market potential for new retail centers[3]. At present, many data sets are presented in gross form for relatively large and often arbitrary areas. Disaggregation is usually impossible, restricting feasible manipulations to aggregation of already gross units.

Compatibility - Compatibility involves the relationships between user needs and (1) the various phenomenon-specific data files within the total data set, and (2) data sets compiled for a number of different urban areas. The first relationship is closely allied to the previous requirement of flexibility. It is necessary to ensure that collected data relate to phenomena of interest to the user, and that data can be made available at levels of aggregation appropriate to the problems being studied. Furthermore, data relating to different phenomena must be available at the same levels of aggregation. Studies of urban structure have frequently been limited by the incompatibility of socio-economic and demographic data compiled for census tracts, and land use data reported for local planning zones[4].

For the second relationship two requirements may be specified. First, data relating to the same phenomenon in different urban areas should be based on the same standard definition. At present, the failure of many metropolitan agencies to adopt standard national definitions is a severe handicap in developing a systematic knowledge of urban structure[5]. Second, data should be available at comparable levels of aggregation for different urban areas.

Reliability - Reliability refers to the accuracy with which properties of real-world phenomena are recorded. Five main factors are considered to affect reliability:

(1) sensitivity of the recording instrument, whether mechanical or human.

(2) capacity of the recording instrument.

(3) expected error of observation of different values of the same property of a given phenomenon. This expected error should be constant. For example, observations on the velocity of traffic flow should be equally accurate at low, moderate and high speeds.

(4) degree of subjective evaluation in the case of a human recorder.

(5) sample design, if coverage of real-world phenomena is not complete.

In particular, the fourth factor creates many problems. For example, it has been pointed out that the number of substandard houses recorded in the 1960 U.S. Census is underestimated partly as a result of using enumerators inexperienced in housing quality evaluation. (Ref. 24)

In addition to the above requirements for the data sets themselves, the question of cost-effectiveness of the collection method should also be raised. Specific data collection projects operate within given budget constraints. Available collection methods should be evaluated with a view to answering the question 'which method comes closest to achieving predefined levels of acceptability for the requirements of timeliness, flexibility, compatibility, and reliability, within the constraints of the available budget?' This statement must be borne in mind in the subsequent discussion, for definitive judgements regarding uses of remote sensors in the urban area must await reliable cost-effectiveness studies both of existing collection methods and of remote sensing techniques.

Inadequacies in existing urban data with respect to the requirements discussed above affect both theoretical and practical aspects of urban research. For example, a fundamental step in the validation of any theory is its empirical testing in a number of comparable situations. To date such testing in the urban area has been restricted to the most simple formulations. The relative lack of sophistication in models of the internal structure of cities has been as much a function of the inability to text complex notions as of the paucity of ideas on the part of the researchers. The models of Burgess, Hoyt, and Harris and Ullman have been discussed in many empirical studies and might be regarded as acceptable conceptual statements at a high level of generality. (Ref. 18) However, once attempts are made to construct models of greater sophistication, requiring detailed data concerning locations and spatial relationships within the urban area, the difficulties of obtaining an appropriate data set are considerable.

II - THE ROLE OF REMOTE SENSORS IN DATA COLLECTION

Properties of Remote Sensors

Remote sensors are defined as optical, mechanical or electrical devices which record data relating to phenomena located at some distance from the recording instrument. The most familiar example of a remote sensor is the conventional mapping camera, whose utility has already received attention in the literature on urban land use[6]. However, other remote sensors are available, whose characteristics and potentialities are less well-known. These characteristics are briefly described below.

The two basic types of remote sensors are passive and active. (Ref. 15) Passive Sensors sample emitted and reflected radiation from surfaces when the energy source is independent of the recording instrument. The recorded radiation includes both reflected solar energy and radiated terrestrial energy. Examples in this category are aerial photographic cameras, thermal infrared and microwave scanners, and spectrometers.

Active Sensors illuminate the surface under investigation with radiation of a particular wavelength and then sample the portion reflected back to the detecting device. Examples include imaging radars and scatterometers.

Specific sensors are designed to be sensitive to radiations within a specified portion of the electro-magnetic spectrum. This range serves to further identify a sensor within the category active or passive. The physical properties of electro-magnetic waves within these different ranges result in different types of data and different data-gathering constraints for various sensors. These properties may be summarized briefly as follows:[7]

Sensors Using Visible Light record types of tonal and textural variation visible to the eye. An optical image, or photograph, is produced (the conventional aerial camera is the best known example of a sensor in this group). At present, these sensors possess higher resolution capabilities than other operational systems; this means that from a given altitude, sensors in this category are able to discern variations of a smaller spatial extent than other systems. Their main disadvantage is that effective operation is restricted to conditions of adequate light and minimal cloud cover; they are "good weather-daylight only" systems.

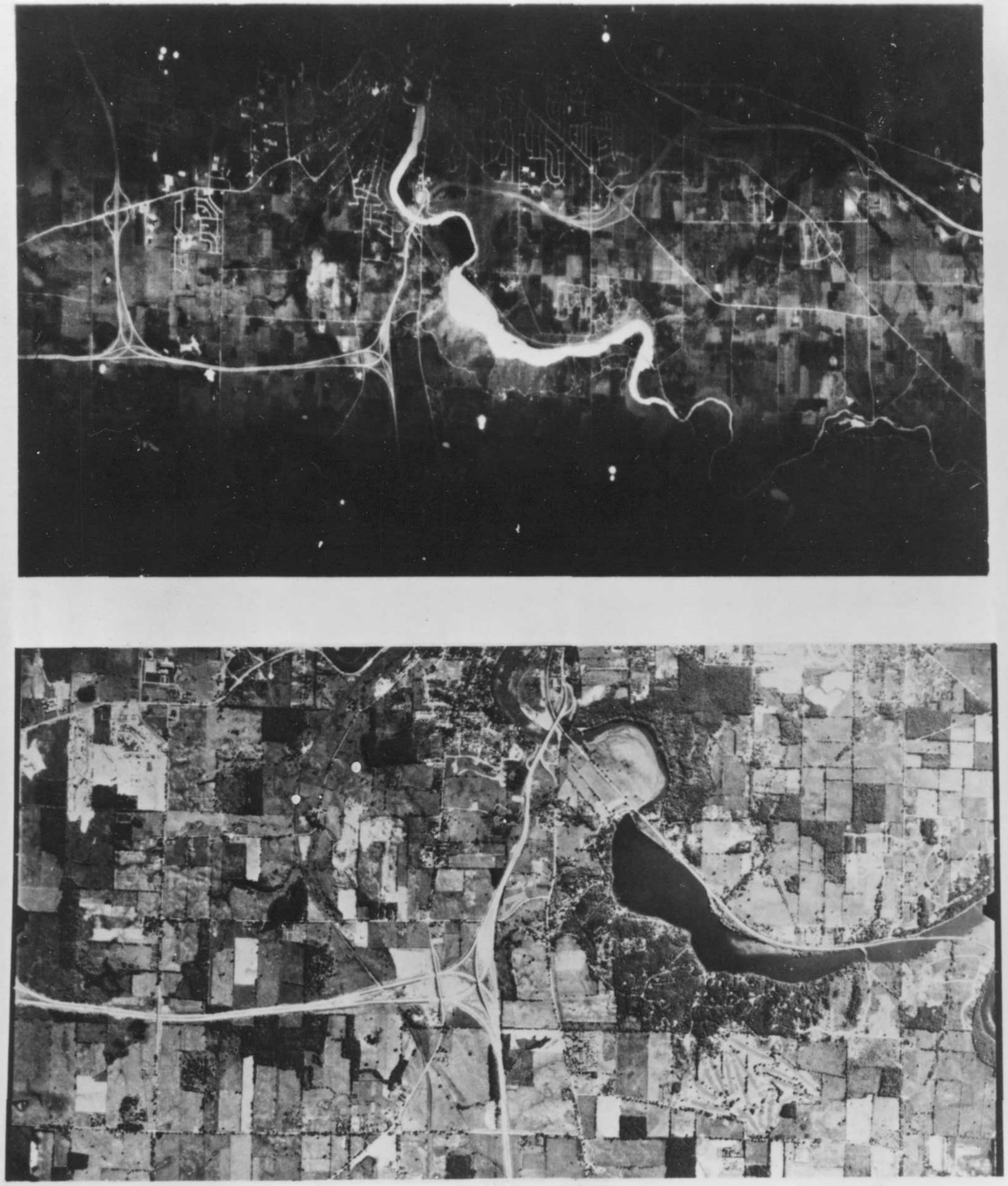
Infrared Sensors register the thermal emissions of objects, recording impulses of longer wavelength than those of visible light. The important difference between these systems and those in the previous group is that radiation levels at different points within the imaged area are recorded electronically, not optically. Production of an electronic image results from further processing of the electrical impulses which provide quantitative statements of the level of radiation at each surface point. Resolution capability is a function of the sensitivity of the original recording equipment; at present, resolution levels achieved by infrared sensors are not as high as for conventional optical systems; however, they are not limited to daylight operation, and they possess some ability to penetrate clouds. An example of an infrared image is shown in Figure 1, together with a comparable panchromatic photograph.

Microwave and Radar Sensors utilize still longer wavelength pulses. Essentially, they measure the roughness of the imaged surface, and by a sequence of operations similar to that for infrared sensors, an electronic image is produced (Figure 2 provides an example). Current imaging radars possess the poorest resolution capabilities among the three sensor types, but they compensate for this by the ability to cover much larger areas in one image than either of the other types of sensor from the same altitude. An important additional advantage is the ability to operate effectively both day and night, and under virtually all weather conditions.

The different properties of these sensors make it necessary to analyze their various returns in order to determine the sensor, or set of sensors, from which the data required for a given problem may be most efficiently obtained. The level of resolution desired and the constraints of time and money are important determinants of the final decision.

The Relationship of the Remote Sensor to an Urban Data System

The following discussion concerns the acquisition and processing of returns from remote sensors operating from conventional aircraft.



WASHTENAW COUNTY, MICHIGAN

Infrared Image

4.5 to 5.5 microns
H (=) 10,000 feet
July 20, 1965

Panchromatic Photograph

0.5 to 0.7 microns
H (=) 13,300 feet
September 14, 1963

(Both images mounted
with South at the top.)

FIGURE 1: Comparison of Infrared and Panchromatic Imagery

FIGURE 2: K-Band Radar Image of the Calumet Basin, South Chicago

Future developments may see their effective operation (from the point of view of urban data needs) from both stationary and orbiting spacecraft; although general principles would remain the same, changes in detailed procedures would be necessary.

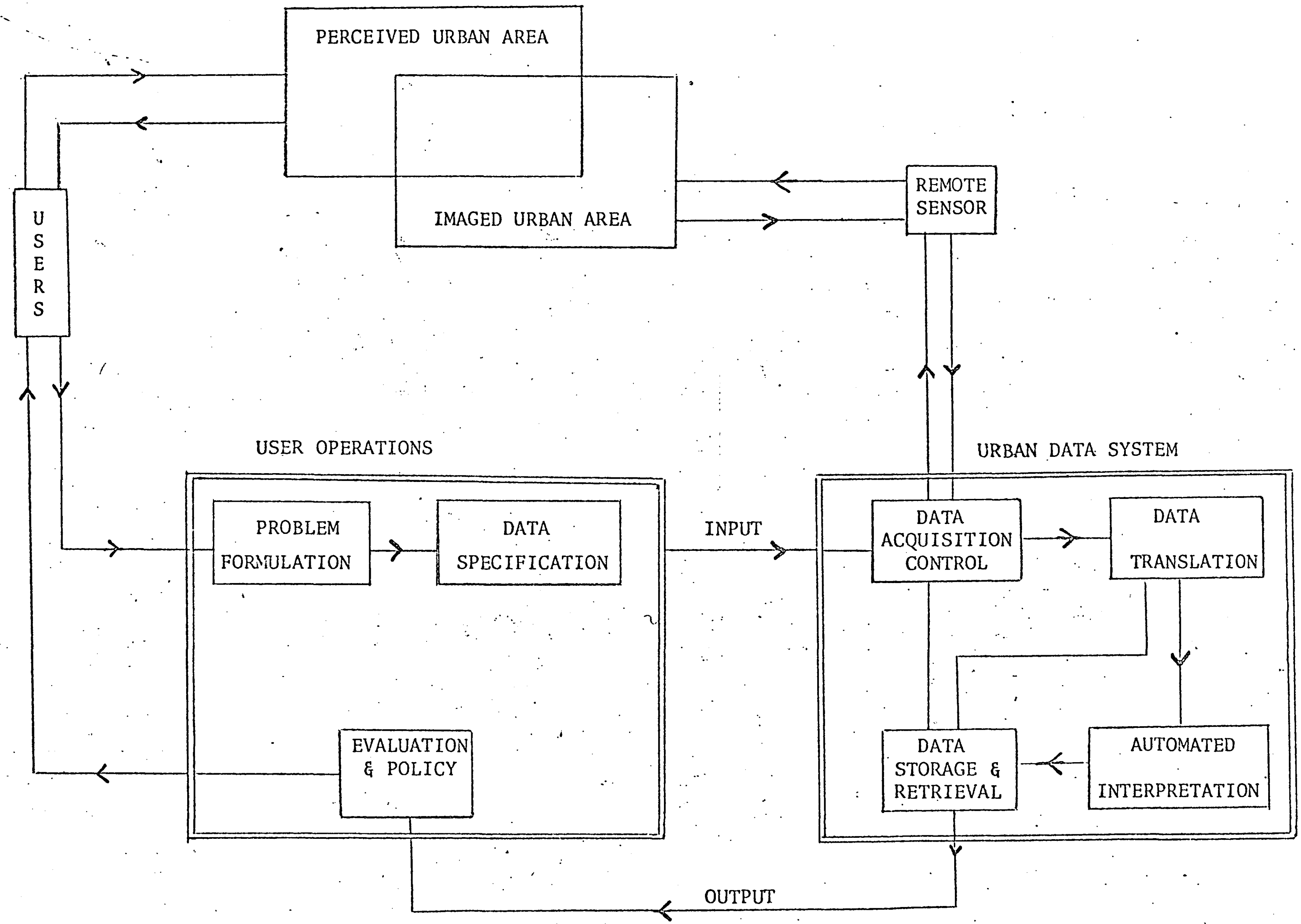
An overflight with a remote sensor produces a certain quantity of imagery of the urban area. Provision of raw data, however, is but one of a sequence of operations in the investigation of a given problem. Furthermore, the interdependence of decisions regarding goals to be pursued, data collected, and hardware utilized require that these operations be structured within an overall framework. This framework may be diagrammed in a number of ways[8]: one such formulation, in which remote sensing is the means of data collection, is given in Figure 3.

In the diagram, the initial step is identification of the problem to be studied. This may range from simple updating of a land use map to making complex policy decisions relating to urban renewal; however, it is the detailed formulation of the problem which permits specification of the data required in its solution. Included in these specifications are scale requirements (the level of detail desired) which determine the optimum altitude for the overflight. In addition, the user specifies the time and flight path of the run. All of this information proceeds as input to the Urban Data System.

The function of 'Data Acquisition Control' is to program technical details of the overflight. This implies pre-flight testing of the equipment, monitoring of the equipment during the flight, and subsequent checking of the technical quality of the imagery.

The output of the overflight is a set of optically or electronically produced images. From the point of view of interpretation, it is important

Figure 3. A FRAMEWORK FOR THE COLLECTION AND PROCESSING OF URBAN DATA USING REMOTE SENSOR IMAGERY



to realize that there is a difference between the data contained in a given image and the data that could be collected by a ground observer. Both data sets are assertions as to what exists in the study area; however, data recorded by the two collection methods are not the same. The imagery is sensitive to the sensor's perspective relative to the ground and to prevailing atmospheric conditions, whereas the ground observer's perception of the study area is a function of his socio-economic characteristics, personal experience, and visual acuity. The two data sets overlap (as indicated in Figure 3); one concern in interpretation is to determine elements which are common to both.

Subsequent processing of the images may proceed in a number of ways. For example, visual analysis may be undertaken by experienced interpreters; extracted data and images may be filed, to be used at a later date to record changes over time by visual comparison with imagery from another overflight. For small, specific projects such as the calculation of the acreage of vacant lots within a limited area of the city, this procedure may be sufficient; however, when considerable amounts of information are required for large areas of the city, visual interpretation is frequently too slow.

To identify the magnitude of the interpretation problem, consider a program designed to obtain conventional aerial photographic coverage of Chicago from a height of 3000 feet, using an RC-8 mapping camera[9]. Chicago measures 20 miles (E-W) by 50 miles (N-S), covering an area of approximately 1000 square miles. From an altitude of 3000 feet above datum, the RC-8, which has a field of view 74° square, will image a band approximately 7/8 mile wide along the flight path. Assuming a 20% overlap on each N-S run, 30 lines would be flown, producing about 1600 photographs.

In comparison, the acquisition of complete coverage from the same altitude using a multiband camera greatly magnifies the problem. This system has a 21° square field of view, and simultaneously exposes nine frames for each imaged area[10]. (An example of one such image is given in Figure 4.) An overflight at 3000 feet would generate 270,000 images. A study of Figure 4, which is a multiband photograph taken from 3000 feet, shows that the level of detail obtained is extremely fine. An increase in altitude will reduce the level of detail, but it will also reduce the total number of images produced. However, even at 10,000 feet, where the same number of flight lines (30) as for conventional coverage at 3000 feet would be needed, the total is still over 14,000.

To cope with this quantity of imagery it is necessary to develop automated methods of interpretation. What is needed is a translation of data contained in the image into a numerical form amenable to processing by modern computer techniques. One method of accomplishing this is by use of a micro-densitometer[11]. This instrument scans the negative of an image line by line with a very small light spot; the amount of light which passes through the negative produces an electrical impulse whose magnitude is a function of the density of the negative at the point of impact of the light spot. The image is thus described by a line by line sequence of numerical values representing variations in density of the negative. These values may be punched on cards, or stored on tape in sequence, transferred to a computer, and subjected to analysis.

The use of automated methods involves two factors. The first is the development of suitable interpretation algorithms for automatic recognition of different types of phenomena. At present only a few elements of the urban scene can be reliably identified[12]. As research progresses consistent algorithms should become available; with respect to individual problems it will then become a question of programming the system to match the appropriate

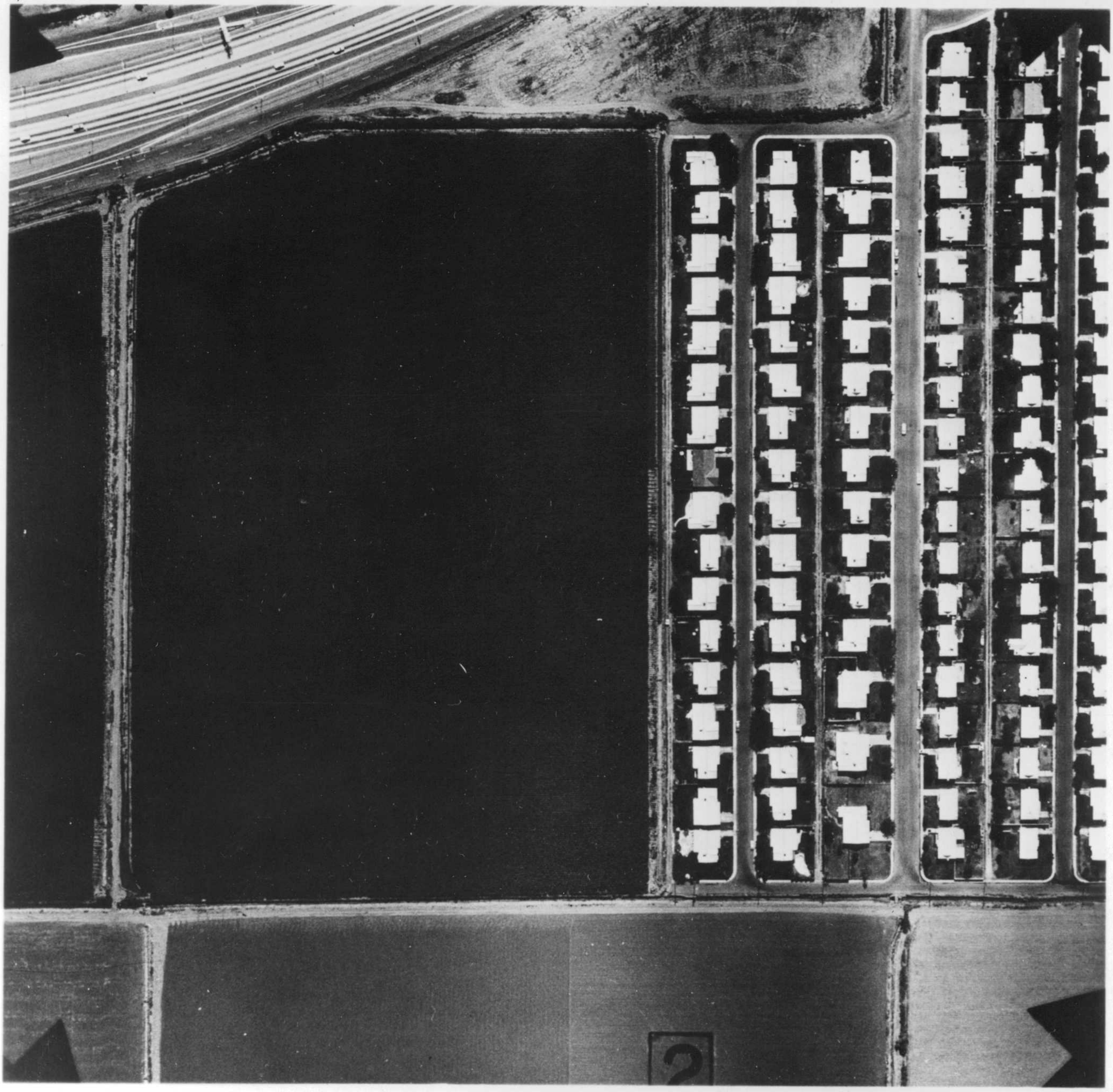


FIGURE 4: Residential Subdivision - 0.45 - .51 mu.

Phoenix, Arizona

Source: Earth Resources Aircraft Program, NASA, Mission #12, Test Site #29, July, 196!

algorithm with specific user data needs.

The second is the development of hardware capable of applying these algorithms to processing the large quantities of imagery produced by an overflight. At present, no system is capable of processing as many as a thousand images within reasonable bounds of time and cost. However, progress in computer technology is sufficiently rapid that some operational capability is anticipated in the near future.

The final demand on the user is to specify the format of output from the urban data system. This does not imply merely the statement of the level of areal aggregation for tables of summary statistics. Recent developments in computer graphics have made it possible to express output directly in the form of maps and diagrams, thus creating a much wider choice of final format[13].

Characteristics of Data extracted from Remote Sensor Imagery

At the present time it is possible to make some general observations regarding characteristics of data collected by remote sensor. These characteristics are discussed within the context of the data requirements outlined at the beginning of the paper. As research continues it will be possible to make more specific quantitative statements, particularly with regard to time and cost involved in attaining given levels of acceptability for each requirement.

Timeliness - Using remote sensing equipment, the period required to gather appropriate imagery for an urban area is relatively short. This ensures a close temporal correlation of individual observations in one data set. Using the example of conventional aerial coverage of Chicago, total flying and turn-around time needed using a Convair CV-240 (the aircraft used by

NASA for its remote sensing experiments) is 18½ hours. Since the RC-8 camera only operates effectively in daylight hours, the program would have to be spread over two or three days. The same amount of time would be required for multiband coverage from 10,000 feet; in comparison, 74 hours would be required for multiband coverage from 3000 feet.

The second aspect of timeliness is the frequency with which complete data sets may be obtained for the same area. With the use of remote sensors, comparable data are required by rescheduling an aircraft overflight at desired time intervals. The relative ease of organizing an overflight is of significance if data are required at short notice; in general, the lag time between decision and effective operation would be shorter than if a field survey had to be planned and enumerators briefed.

Flexibility - Data extracted from imagery are extremely flexible with regard to areal aggregation. The lower bound to the level of aggregation is determined by the resolution capability of the sensor at the altitude of the overflight. As can be seen from Figure 4, this can be made less than the individual land parcel proposed by Clawson as the basic recording unit for land use data.

Compatibility - At present, the most serious restriction to the compilation of extensive data sets using remote sensor imagery is the relatively small number of phenomena which can be identified using automated procedures. This implies that existing compatibility between such data and user needs is limited. However, automatic photointerpretation and pattern recognition is an area of extremely active research, which promises to yield a greatly increased number of automatically identifiable urban phenomena within the next few years[14].

With respect to the temporal aspect of compatibility, remote sensor imagery possesses one significant attribute. If, for a given overflight, data relating to a specific class of phenomenon can be extracted, then theoretically the same type of data can be extracted for comparable previous overflights. Thus, if a problem arises for which historical data on development is needed, recourse can be made to available imagery for previous periods. This presents a marked contrast to Census and survey returns which are designed to record data on a limited number of phenomena; if a certain class of data is not obtained at one point in time, it obviously cannot be subsequently retrieved.

With respect to compatibility of data for different urban areas, remote sensors possess other advantages. The extreme flexibility of extracted data means that the spatial framework pertinent to a given problem can be applied to any urban area, i.e., the level of aggregation is internal to the analysis rather than external. Furthermore, development of automated interpretation procedures based on standard definitions implies that comparability of data is objectively determined for each area.

Finally, establishment of compatibility of data both for the same area at different times and also for different areas at the same time will depend on the determination and recording of appropriate control parameters. For example, the exact nature of returns depends on aircraft altitude, instrument parameters, and existing light and weather conditions. Information relating to these factors can be used to standardize returns for different overflights.

Reliability - For the classes of phenomena for which remote sensors can provide data, three advantages vis-a-vis current methods are cited:

(1) Capacity of a sensor with respect to acquisition of data is higher than that for a field enumerator. For recording static

phenomena, this attribute may not be of great importance; however, for recording dynamic events, such as characteristics of traffic flow, the rate at which events must be recorded may be beyond the capacity of the individual, resulting in unavoidable errors of omission.

(2) Data extracted from imagery can be readily checked. In the case of the enumerator, it is suggested that field checking consumes greater amounts of time (and therefore of money) than remote sensing techniques for comparable data files. Furthermore, for data relating to dynamic events checking is frequently impossible, permitting errors in counting and classification to pass unnoticed.

(3) The problem of subjective evaluation is reduced if imagery can be used in data collection. Potential for consensus is greater for a small number of trained interpreters than for the large body of relatively untrained personnel employed in field enumeration.

One point is stressed: the use of remote sensors does not make the ground survey redundant. The ground survey must be used to provide initial information from which parameters for the interpretation algorithms can be developed; equally important, further ground surveys must be undertaken to prevent systematic errors from accumulating over a lengthy period. The function of the ground survey is to monitor the reliability of data obtained from remote sensor imagery. Therefore, the reliability of extracted data is highly dependent on the accuracy of observation in associated ground surveys.

III - SOME POTENTIAL USES OF REMOTE SENSORS IN URBAN RESEARCH

Discussion in the previous section is concerned with general characteristics of data extracted from remote sensor imagery. At this time, it is also possible to make some specific suggestions as to areas in which this data collection technique might be applied. In general, these suggestions form a basis for future research, and as such it is anticipated that the following comments will undergo considerable clarification and extension as research is pursued.

Each sensor possesses advantages over other sensors for specific purposes as a consequence of operating over a limited range of the electro-magnetic spectrum. However, in evaluating the potential utility of a remote sensing system, it is not sufficient to ask whether that sensor is capable of acquiring imagery from which a specified data set can be extracted. The fundamental question is whether the sensor is capable of providing the desired data, which satisfy the criteria of timeliness, flexibility, compatibility, and reliability more rapidly, more accurately, or with lower costs than other available collection methods.

With respect to measurement, two types of data may be recognized: (1) data on static patterns, such as arrangement of facilities or land uses, and (2) data on dynamic patterns, such as the movement of people, commodities, and information. These two classes of data have been related to recommended types of sensing capability, namely "on-demand" and "real-time" systems.

> "The earth itself may be regarded as a storage bank for much information, with data from remote sensors available 'on-demand.' For many static urban features, where storage of information might be expensive, "rediscovery" of the information on demand, by interrogation of an information system linked to...orbital sensors, might be an expedient solution. Examples of applications include inventories of structures for tax purposes and sufficiency ratings for roads and streets.
>
> ....
>
> A number of urban elements change form or position rapidly, and knowledge of these changes is important. An example is urban traffic. Almost instantaneous information on shifts in the state of the traffic stream is a requisite for control or emergency actions. Many traffic-related research questions require continuous data on flow characteristics. Real-time surveillance would be desirable in fire detection and control, air pollution detection and warning, dispatching of vehicles and

(identification of) building construction starts." (Ref. 19)

Since the properties of different sensors are associated with the capability of collecting different types of data, potential uses are discussed in relation to specific sensors.

Three types of sensor are considered; the multiband camera, thermal infrared systems, and imaging radars.

1. The Multiband Camera

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 range of the electromagnetic spectrum). In the multiband system, 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)[15].

The main advantage of this sensor is the high degree of resolution which can be achieved. In addition, the plate-to-plate variation for simultaneously exposed images provides a detailed base for interpretation of returns. The tonal variation of a given element for the sequence of images is termed its spectral signature and forms an important component in identification of the corresponding element on the ground[16].

Since the system depends to a great extent on visible light, it possesses a basic limitation in that its effective operation is restricted to 'good-weather-daylight only' conditions. A further disadvantage, as has been noted above, is the large quantity of imagery produced for an overflight at low to moderate altitudes. These comments suggest that the multiband camera is best suited to large scale surveys in which exact timing is not critical. In other words, it is suited to providing 'on-demand' data.

The basic application of this sensor is in the updating of specific inventories for urban areas. This would provide the basis for making more rapid policy decisions to counteract adverse changes in many aspects of urban life.

Two types of inventory may be defined:

(1) Inventories for which required data may be extracted directly from imagery. Examples are the compilation of road and street characteristics, locating new buildings of different types, and mapping the spread of urban blight.

(2) Inventories for which the existence of the phenomenon has to be inferred from the presence of other features known to be consistently associated with that phenomenon. An example of an 'inventory by surrogate' compiled from imagery is provided by Wellar's study of housing quality in Chicago. (Ref. 25) In this study particular attention is paid to the identification of areas of substandard dwellings. It is found that certain environmental characteristics such as the presence of litter, lack of playing space, and unkempt yards are consistently associated with low quality housing. These environmental characteristics are readily identifiable on the multiband photographs; in particular, returns in the near infrared range of the spectrum are found to be significant in providing reliable identification. Since current methods of evaluation and mapping of a variety of urban data consume considerable amounts of time and money, multiband imagery would seem to possess the potential for a considerable

contribution in this field.

It is again stressed that use of multispectral photography in compiling or updating inventories does not exclude the ground survey. The type of survey design envisaged for a project such as the regular updating of a city land use map might encompass conventional ground coverage every five years associated with annual overflights with a multiband camera. If subsequent research shows that the degree of reliability of multiband data is extremely high, full coverage every five years might be replaced by carefully controlled areal sampling with the remote sensor being used for the bulk of data collection.

At the level of visual interpretation, multispectral photography is able to provide detailed and more accurate urban land use data than any other available system. It is also suggested that the number of man-hours required to extract land use date from multiband imagery is substantially less than for existing field survey methods, although controlled experiments are necessary to verify this contention.

The capability of the sensor to obtain coverage of the urban area at frequent intervals means that changes in urban land use could be monitored much more effectively than at present. The urban geography panel at the Houston meeting on uses of spacecraft in geographic research commented that 'settlements change form and function faster than conventional measurements can monitor and the nature of the urban problem has transcended the ability of almost all contemporary monitoring systems' (Ref. 19). It is anticipated that the multiband camera will provide a greatly increased capability to cope with the problem of rapidly changing urban structure.

2. Thermal Infrared Sensors

Thermal sensors produce electronic images compiled from a sampling of radiations within the spectral range 8 - 14 microns. The data collected essentially relate to differences in surface temperatures within the imaged area.

At present, it is more difficult to make definitive statements regarding the potential usefulness of thermal sensors than for any other system. There are two basic reasons for this:

(1) lack of familiarity of urban scientists with the technical details of the infrared sensors, and

(2) lack of imagery available for general use[17].

Despite these drawbacks it is useful to consider the characteristics of returns from this sensor in greater detail. By so doing, a better perspective will be provided for the subsequent discussion of potential uses and problems

In an urban environment there are several ways in which radiant energy is emitted. Solar insolation may be absorbed by objects (natural and man-made) and later emitted. Sources of non-solar radiant energy such as burning waste-heaps, slag piles, and smokestacks radiate directly into the atmosphere. Other sources of non-solar energy (furnaces, stoves, engines, etc.,) result in the emission of radiant energy from walls and roofs of buildings in which they are located.

Surface temperature variations which are detected and measured are determined by many factors, such as the following: the heat capacity of objects, their thermal conductivity, their surface-to-volume ratio; their surface composition (e.g. texture, pigmentation), the angle of incidence of solar radiation, previous levels of radiant energy, and previous weather conditions. Any one of these factors, or even a combination of factors may predominate in a given situation.

In addition to these sources of surface temperature variation the measurement from airborne platforms of radiation emitted from earch surfaces (both natural and man-made) is affected by the state of the atmosphere separating the surfaces and the recording instrument. Furthermore, consideration must be given to the distance between the emitting surfaces and recorder (the altitude of the aircraft above datum), and deviations from the vertical of the line of sight from recorder to surfaces.

Control problems are greater for thermal sensors than for any other imaging system. They considerably complicate identification procedures For example, the temperature of an automobile is a function of its own internal head source, its velocity, the heat created by friction between tires and road surface, direct solar insolation, the temperature of the air, and radiation from other nearby objects. Thus, a statement such as "if we consider that roads carrying a greater flow of vehicular traffic have a higher temperature than roads with flow considered normal, and if methods of simultaneous imagery were accomplished so that area-wide patterns could be established, it might be possible to obtain valid information about traffic migrations within a given area on a round-the-clock basis"[18] would require a great deal of research before they could be substantiated. In fact, in view of existing methods of data collection, it is doubtful if such a traffic study could be reasonably justified.

A more plausible use of thermal sensors, given existing techniques, is the study of air and water pollution, provided that the pollutants studied are known to create thermal differences in the atmosphere or in the relevant water body. These differences would be on a sufficiently large scale to be identified on current imagery. The capability of obtaining imagery at frequent intervals both day and night would permit the determination of the direction and degree of spread of pollution from a given source under measureable meteorological conditions. Control problems still exist (for example, the effect of radiation from different land use types within the city), but these are not as severe as in the case of traffic flow studies.

Thermal sensors possess an advantage over the multiband camera in being capable of night-time operation. However, unless temperature variations of elements within the urban area are of major importance in interpretation, radar is likely to prove the more useful night-time system.

3. Imaging Radars

Most of the suggested uses of radar in the urban area are a direct consequence of its ability to operate effectively under virtually all weather conditions both day and night.

Imaging radars possess the capability of providing both "real-time" and "on-demand" data. However, comments relating to the former depend on the assumption that it will be possible either to install these sensors on stationary satellites located over large urban centers, or to operate the systems from aircraft for extensive periods[19].

Real-time data are essential to the monitoring of intra-urban flows, particularly for the case in which control decisions having immediate effect need to be made. Traffic-flow studies provide an example of the potential use of this sensor. Almost continuous information on the nature of a traffic stream in critical rush-hour periods is required if appropriate action is to be taken to prevent or disperse congestion. One method of obtaining this information is to utilize data feedback from airborne or spaceborne radar.

It may be argued that conventional methods of collecting real-time traffic data are equally promising. However, one advantage of the radar is that a comprehensive picture of road conditions is provided at one point in time, as compared with most existing techniques which obtain samples of traffic passing given points in unit time. The comprehensive coverage permits estimates to be made of the amount of traffic feeding into key points in the road net, and also permits the rapid identification of major interruptions to flow (particularly accidents). Furthermore, it is possible that identification procedures will be developed to differentiate between vehicle types. This would allow an assessment of the relative contributions of private automobiles, trucks, and public transport vehicles to a given traffic stream.

Utilization of such a system exerts other demands. Development of suitable automated methods of data interpretation and processing are more critical with respect to the handling of "real-time" than "on-demand" data. In the traffic-flow case, it would be difficult to make traffic-control decisions from visual inspection of imagery for the vast number of sources of potential congestion in a large urban area. Development of procedures to handle data in real-time situations implies not only the establishment of reliable identification methods for vehicles, but also the development of effective methods of selectively recording traffic data.

Within the framework of traffic studies, other uses of radar can be identified. For example, it could be employed to investigate the impact of major interruptions to flow over time, particularly to determine the spatial extent of the influences of serious accidents. Relatively little is known about flow characteristics in fog; radar could be used to provide detailed data on this phenomenon.

Many other types of data on dynamic patterns can be obtained using radar. For example, valuable information regarding the relative attractive power of adjacent suburban shopping centers could be acquired by monitoring the hour-by-hour build-up of cars in associated parking areas. In a similar vein, the impact of new centers on shopping behavior could be assessed; data could be obtained on the initial attraction of new shops, the time taken for travel patterns to stabilize, and the overall influence on other centers in the area. The advantage of this remote sensor over other methods is that such data can be acquired at any time, particularly at short notice, and over time periods of any desired length.

The capability of radar to acquire "on-demand" data is illustrated by a study of Figure 2. Most of the major urban land use types can be identified (residential, industrial, commercial, and open space) as well as the main elements of the transportation network. More reliable interpretation procedures may depend on the use of several spectral ranges instead of a single range in a manner analogous to that used for multispectral photographs. In addition use may be made of the ability to polarize the emitted signal in two directions, giving up to four different images for the same area for a given spectral range. Although it is not anticipated that identification will be superior to that for the multiband imagery, the all-weather capability is an important consideration if flying schedules are to be maintained. For example, if land use inventories are to be updated on a monthly basis, weather conditions may prevent the use of the multiband camera. If an aircraft is used, it is virtually impossible to set tight schedules using visible light systems; furthermore, it is an expensive proposition to maintain crew and equipment in a state of readiness for several days waiting for suitable flying conditions. All of these factors favor the serious consideration of radar as a means of acquiring "on-demand" data.

The discussion so far has centered on the acquisition of imagery that is comparable in format to that obtained by conventional photography. There are, however, additional properties of radar sensors which may be used to obtain data on aggregate movement, on velocities, and on routes followed by specific objects.

First, it is possible to selectively record those objects in a given imaged area which are in motion[20]. At a high level of resolution individual vehicles will be resolved; the arrangement of the high return elements will tend to be linear corresponding to the road network in the imaged area. At a coarser level of resolution, average intensity of returns for arbitrary areas (for example, the squares in an appropriate grid overlay) may be computed to yield surrogates for aggregate movement in those areas. Comparison of average movement values for all areas at one time, and for single areas at frequent intervals throughout day and night would provide valuable information on aspects of travel behavior in the urban area.

Second, it is possible to artificially amplify or modulate the radar signal returning to the recorder from specific objects, permitting reliable identification of these surface objects from the return signal pattern[21]. Continuous operation of a radar system would permit the tracking of routes of "tagged" vehicles (vehicles fitted with signal modification devices) and the determination of their velocities from sequential images. If it proves to be possible either to obtain suitable resolution levels from a stationary satellite or to operate the system from an aircraft for extended periods, much more reliable data on individual travel behavior could be acquired, particularly relating to route selection and travel times. This would help to overcome some of the deficiencies of existing "travel diary" methods which suffer from the lack of reliability associated with most recall data.

The above comments indicate that a great deal of research is still needed before the full utility of radar in the urban area can be realized. Research is necessary both with respect to technical development of specific sensors and to the more rigorous structuring of experimental applications. However, based on the basic properties of the system and on the preliminary research undertaken to date, it is contended that radar possesses a greater potential utility for urban research than any other available sensor.

CONCLUSION

This paper provides an introduction to the use of remote sensor imagery cast within a broad framework of requirements for urban data. It was shown that remote sensors possess particular advantages with respect to the criteria of timeliness and flexibility, and that the attainment of acceptable levels of compatibility and reliability depend on further research.

The different properties of different sensors provide data which complement rather than replicate each other. Furthermore, as technological advances are made, yielding better imagery outside the visible range of the electro-magnetic spectrum, our ability to identify and interpret will rapidly improve. In addition, non-visible systems provide data on dynamic patterns, thus greatly extending the utility of remote sensors in the urban area. The potential value of remote sensors is not in question; the major task is to develop and utilize this potential in the most efficient way.

NOTES

1. For example, Clawson (Ref. 3,4) examines the requirements for land use data in general. Thomas (Ref. 20) considers urban data and urban information systems in particular: much of the discussion relating to urban data requirements is based on the latter study.

2. However, the data collection period for the United States Census of Population and Housing in 1960 extended from March 31 past April 30, although more than 95% of data were collected by April 15 (Source: United States Census of Population and Housing, 1960; Enumeration Time and Cost Study, U. S. Department od Commerce, Bureau of the Census, 1963).

3. This point has been made by Garrison (Ref. 10) in referring to the need for small-area data

4. Clawson (Ref. 4) elaborates on this point. See Ch. VI, particularly p. 102.

5. A good example is provided by Wellar (Ref. 25) who points out that the definition of housing quality varies considerably from one city to another. The point is also discussed by Clawson (Ref. 3, p. 674).

6. The most comprehensive study is that by Branch (Ref. 1).

7. For a more complete discussion of the uses and limitations of the different classes or sensor, see Leonardo (Ref. 12).

8. This particular breakdown is the one considered by the authors to be of heuristic value; other discussions of urban information systems have used different, although related subdivisions. See Campbell (Ref. 2) and Thomas (Ref. 20).

9. For details of the RC-8 camera, see 'Airborne Photographic Equipment,' Defense Documentation Center, AD452117, p. 90.

10. For details, see 'Itek Nine-Lens 70-mm Multiband Camera' - Model 2 Operating Instructions, Vidya Corporation, Palo Alto, 1965.

11. Discussion of the operation of a micro-densitometer is provided by Moore et al (Ref. 14).

12. Research effort to date has largely been focussed on methods of automatic interpretation. Some success has been achieved in this research in differentiating between different types of road and street surfaces, rooftops, and elementary land uses. See Schneider (Ref. 17) and Dueker (Ref. 8).

13. Colner (Ref. 6) provides an example of land use plotting. Tobler (Ref. 21) discusses the question of computer mapping in more general terms.

14. Examples of this research are provided by Dalke (Ref. 7) and Rosenfeld (Ref. 16). An overview of pattern recognition in general is given by Uhr (Ref. 23).

15. For a more detailed discussion of the multispectral system, see Molineux (Ref. 13)

16. Many examples of the use of spectral signatures are contained in the Proceedings of the Third and Fourth Symposia on Remote Sensing of Environment, Infrared Physics Laboratory, University of Michigan, Ann Arbor, 1964 and 1966. see, for example, Legault and Polcyn (Ref. 11).

17. Most thermal infrared imagery is classified. That which is available is generally of poor quality.

18. This statement is contained in a general discussion of the applicability of thermal infrared techniques by Estes (Ref. 9)

19. The feasibility of extended airborne operation was pointed out by Mr. G. Towner of the Westinghouse Corporation (personal communication)

20. This refers to the system known as the Moving Target Indicator (MTI)

21. This technique has mainly been developed using longer wavelength radio systems: see, for example, Cochran et. al. (Ref. 5)

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