Examples of Remote Sensing Applications to Engineering

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•MOST observations that can be made with remote sensing systems can provide information that is relevant to engineering endeavors. Figure 1 shows the basic parameters that may be "observed" with operational and/or experimental devices operating in one or more parts of the spectrum or one or more "dimensions." The dimensions of remote sensing include (a) the spatial dimension, (b) the spectral dimension, which includes two sub-dimensions—polarization and luminescence, and (c) the dimension of time. The ability of the scientific community to interpret items of engineering significance from remote sensor data varies greatly from one part of the spectrum to another and from one dimension to another. The purpose of this paper is to summarize the state of the art in each of the major spectral increments and dimensions and to discuss the engineering value of these classes of observations.

SPECTRAL/SPATIAL DIMENSIONS

Systems making use of the spectral/spatial dimensions of remote sensing include cameras, optical-mechanical scanners, and radar and microwave imaging systems. General comments on each of the commonly used systems follow.

Panchromatic Photography (or Television)

Panchromatic photography is the most widely used remote-sensing technique because of its availability, relatively low cost, and high information content. Interpretive and mensuration techniques are well developed and it is widely used for mapping. Formal training in its use for engineering and other purposes is available.

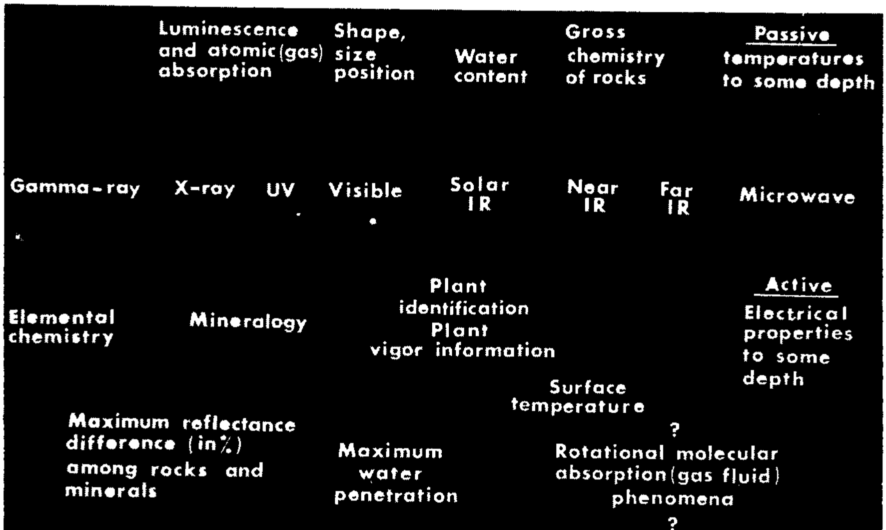


Figure 1. General types of information that may be obtained from observations made in various parts of the electromagnetic spectrum.

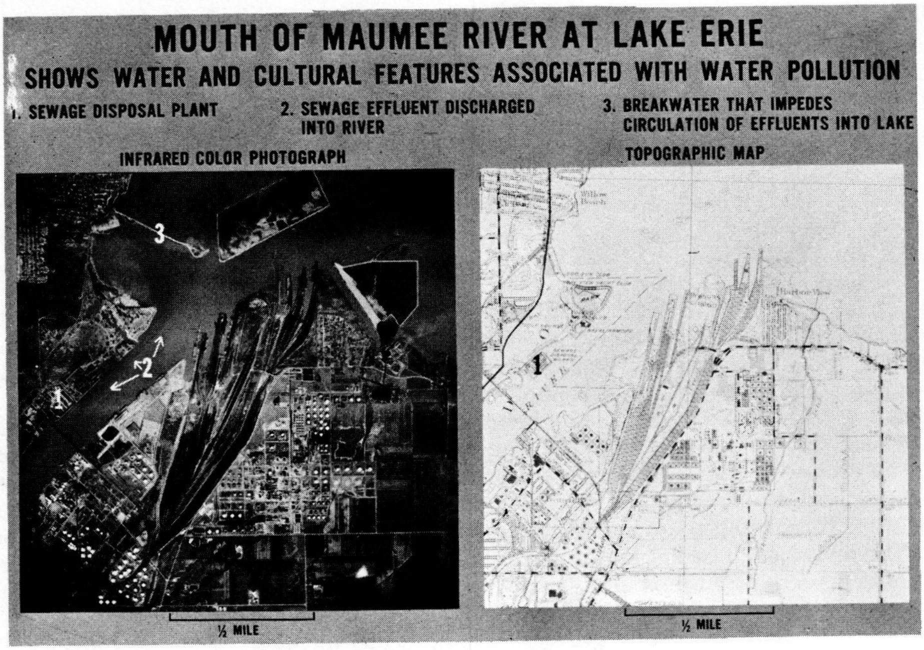


Figure 2. Black-and-white copy of an infrared color aerial photograph showing distribution of pollutants in Maumee Bay; the sewage plant (1) discharges effluent (2) into Maumee Bay that is trapped behind the recently built breakwater.

Infrared Photography (or Television)

Infrared photography is primarily of value in mapping drainage features and shorelines. Water is always black in a positive print. Some vegetation characteristics are discernible that are, in turn, valuable in land-use determinations. The presence of vigorous vegetation (characterized by high infrared reflectance) may, for example, denote high soil-moisture conditions.

Color Photography (or Television)

Color photography, in spite of its built-in spectral redundancy, promises to be a major tool of the earth scientist in many special fields, and is sufficiently better for recognition of significant features such as soil types and underwater features that it may replace panchromatic photography for many engineering uses.

Infrared Color Photography (or Television)

Infrared color photography may be superior to standard color photography for many purposes. It shows differences in vegetation and vegetation vigor more clearly and provides a slightly higher contrast on water surfaces than conventional color. Infrared color is also useful for "seeing" alien fluids in water. Figure 2 is a black-and-white copy of an infrared color photograph of the Maumee River in Toledo, Ohio. The distribution of effluents from a sewage treatment plant is clearly visible.

Ultraviolet Imagery

Reflectance contrasts among many natural objects are commonly greater in the ultraviolet than in the visible part of the spectrum. Thus, ultraviolet imagery acquired with scanners or cameras may be especially useful for discriminating rock and soil types. Spectroscopic measurements suggest that the reflectance of rocks that have a high silica content decreases rapidly with decreasing wavelengths in the ultraviolet, in

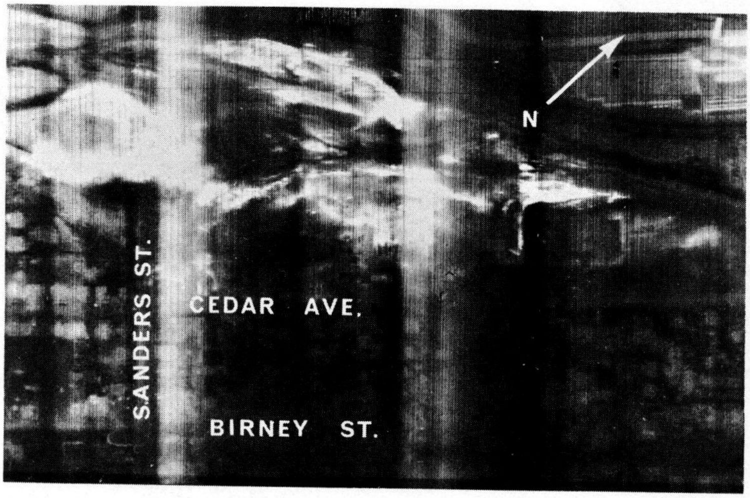


Figure 3. Infrared image of a portion of Scranton, Pa., showing thermal anomalies associated with burning culm banks and underground mine fires; the rectangular anomaly in the right-central part of the image outlines a bowling alley—since removed.

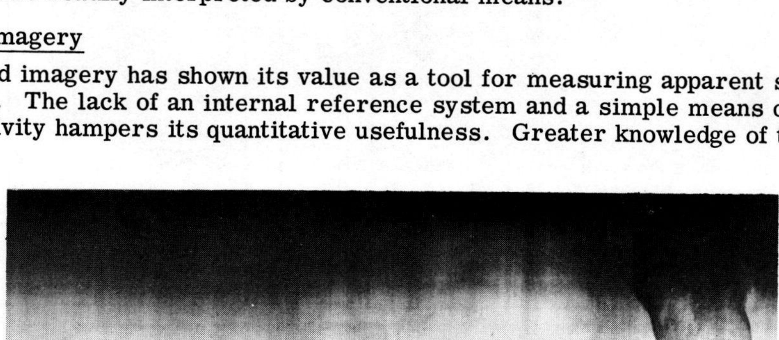
contrast to basic rocks whose reflectance changes little with decreasing wavelength. Multispectral systems recording in the ultraviolet may permit gross rock type identification.

Multispectral Photography (or Television)

Multispectral photography is commonly acquired with 9-lens cameras or clusters of lesser numbers of small cameras. Interpretation of multispectral photography requires a background of spectral-signature studies of terrain and water features that has been developed only in part. Data returns from some multispectral systems are voluminous and cannot be readily interpreted by conventional means.

Infrared Imagery

Infrared imagery has shown its value as a tool for measuring apparent surface temperatures. The lack of an internal reference system and a simple means of determining emissivity hampers its quantitative usefulness. Greater knowledge of the physical



Infrared image obtained with a line scanning radiometer. 8-13 micron band.

The infrared image records the patterns of cool surface and ground water discharge into warmer ocean water. This method may be applied to the locating of new sources of fresh water along coastal areas.

Figure 4. Infrared image of fresh water discharge into ocean, Balayan Bay, Luzon Island, Philippines.

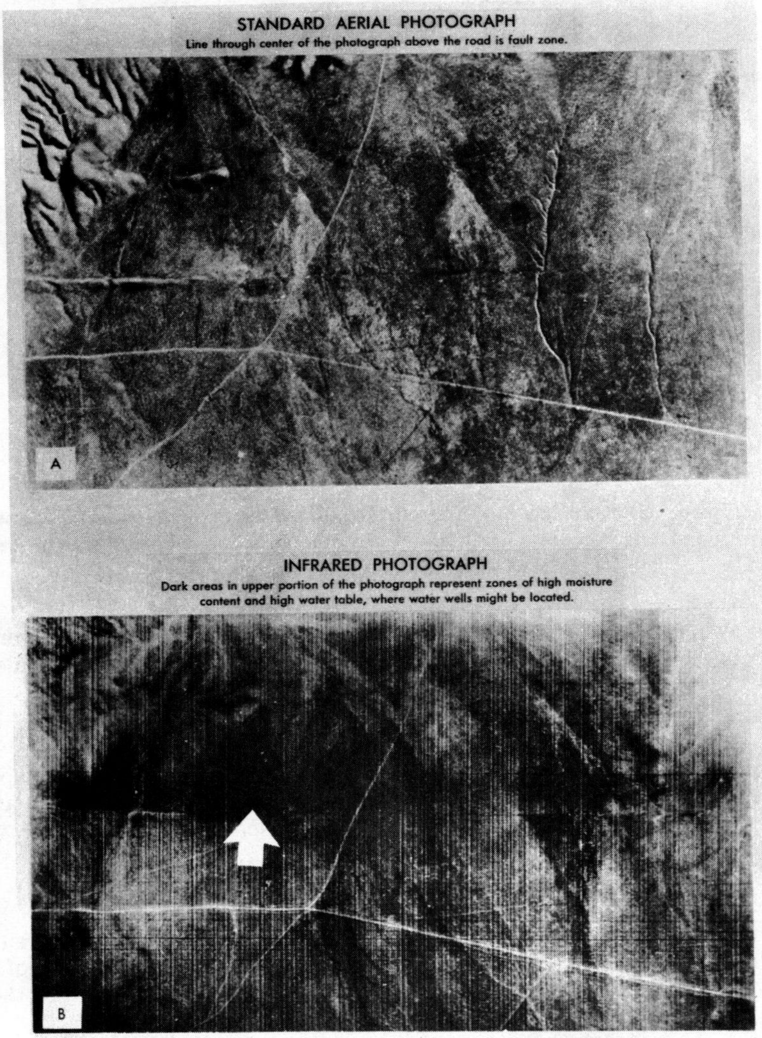


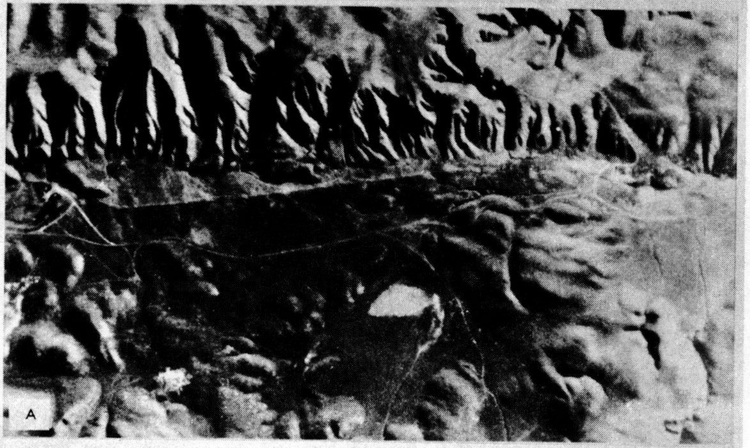
Figure 5. An infrared image of a segment of the San Andreas fault; the temperature difference on either side of the fault has been interpreted to reflect differing proximity of the water table to the surface.

and chemical parameters that have an effect on radiant temperatures needs to be developed to assure proper use of the reduced data. Infrared imagery is becoming routinely applied in surveys of abnormal geothermal features, such as volcanos and underground fires. Figure 3 shows thermal anomalies associated with burning culm banks and underground fires. Images of this type are helpful in planning control of at least some mine fires.

Infrared scanners have proved particularly useful in imaging the distribution of fresh water springs issuing into the ocean and streams; Figure 4 shows one example of such an image. Scanners have been used in highway route surveys of thermal areas and to map concealed fault structures and local differences in the proximity of the water table to the surface (Fig. 5). Areas having abnormally high soil moisture content and considered to be landslide prone have also been located from infrared images (Fig. 6). Flown repeatedly at different times of day, infrared images provide information on the "compaction" of the surface. Scanner data are difficult to relate to map positions.

STANDARD AERIAL PHOTOGRAPH

Standard aerial photography gives few clues to the presence of landslide-prone areas.



INFRARED IMAGE

Dark areas identified on the photograph by arrows represent soil that has moved as landslides toward the upper portion of the photograph. Difference in tone result from moisture trapped in the slide soil.

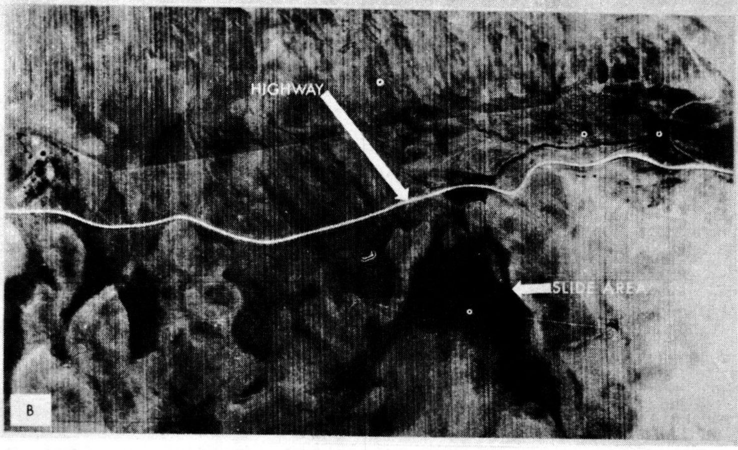


Figure 6. Areas believed prone to landslides are distinguished from stable ground through differences in soil moisture content; the ability to identify these areas near highways, residential areas, and industrial construction and to make the information available quickly would have obvious benefits.

Multispectral, Optical-Mechanical Scanner Imagery

Multispectral, optical-mechanical scanners permit data to be acquired throughout a broader band of the spectrum ($\sim 0.3\,\mu$ - $16\,\mu$) than photographic systems. Data can be acquired simultaneously in 18 or more channels. The resulting high data rates require use of automatic data processing techniques. Such a system has been used to automatically survey distributions of water, agricultural crops, rock types, houses, and other cultural features. Automatically processed, multispectral scanner data hold high promise of aiding in land-use surveys.

Radar Imagery

Radar imagery is an excellent tool for all-weather coverage of large areas. It has demonstrated value in mapping structural features, has been of some use in differentiating crops and rock types, and has delineated areas of abnormal soil moisture.

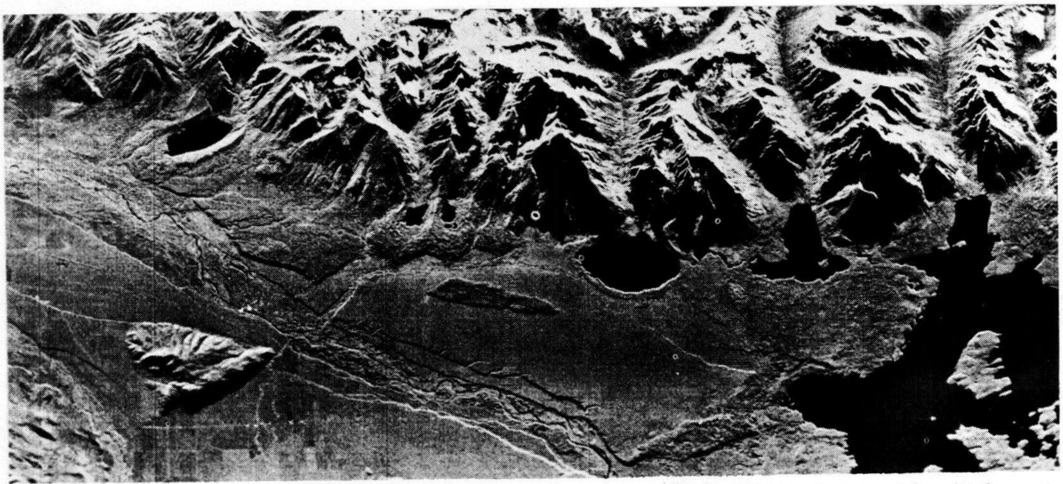


Figure 7. A radar image of an area near Jackson Hole, Wyo.; note the clarity with which some geomorphic features such as terraces and kames are shown.

Geomorphic features such as eskers, terraces, and old stream channels often show clearly on radar images (Fig. 7). It is quite usable for small-scale planimetric charting, especially as an adjunct to conventional maps. As longer wavelength radars become available, they may permit detection of some subsurface features.

Passive Microwave Images

Passive microwave images record energy emitted from the earth in the radio frequencies. The quantities of energy emitted depend on the temperature of the object and its emissivity. Temperatures and emissivities are integrated to some depth. Systems may be useful for mapping soil moisture distributions. The wide range of emissivities of materials in this part of the spectrum suggests that microwave observations may be useful for identifying solids and fluids. Recent research suggests that microwave images may provide sea-state information on lakes and oceans. Much laboratory work remains to be done before the data can be used effectively for engineering or resources purposes.

SPECTRAL DIMENSION

Systems making use of the spectral dimension are nonimaging in the conventional sense. They include spectrometers, radiometers, and interferometers. Commonly, these systems are more easily calibrated than imaging systems and make useful adjuncts to images. Following is a description of those under intensive study.

Infrared Radiometry

Infrared radiometry is very useful for sequential measurements of changes in land and water surface temperatures because it is a simple measurement technique and data reduction is simpler than for infrared imagery. Some systems used multi-wavelength arrays. Radiometry is routinely used for periodic radiant temperature surveys of near-shore oceanic areas. These data are commonly recorded on conventional strip charts.

Infrared Spectral Radiometry

Infrared spectral radiometry measurements are made with spectrometers, interferometers, and filter-wheel radiometers. Observations have meaning with respect to plant identification, rock composition, and apparent surface temperature. Wavelengths

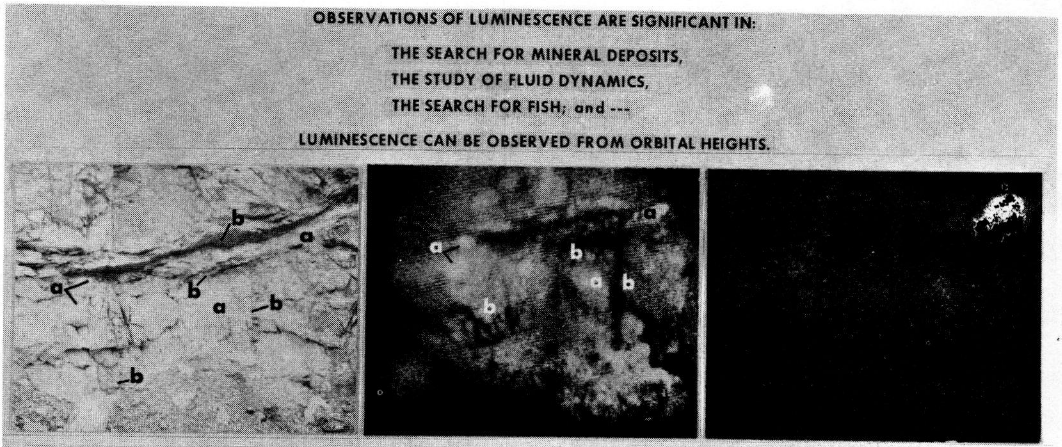


Fig. 1. Conventional photograph of a quarry face near Baltimore, Maryland.

Fig. 2. Image of same area as Fig. 1, recording both reflected ultraviolet energy and ultraviolet stimulated luminescence, shows, a - luminescing mineral (deweylite, a hydrous magnesium silicate) and b - fractures.

Fig. 3. Image of same area as Fig. 1 and 2, recording only UV stimulated luminescence (deweylite)

Figure 8. Example of observation of luminescence as an aid in geologic study.

observed are from 1 to 16 μ. Computer-stored libraries of "spectral signatures" are being compiled. Some systems have a field-of-view of 1 deg or less and integration times of $\frac{1}{6}$ sec or less.

Passive Microwave Radiometry

Passive microwave radiometry is a means of measuring apparent temperatures at selected frequencies in the radio spectrum. Multi-wavelength arrays are commonly used. Depth to which temperatures are integrated is a function of wavelength; the longer the wavelength the greater is the "penetration." Passive microwave radiometers have been used successfully to detect subsurface voids and are being tested extensively to affirm their usefulness for measuring water content of snow. Microwave radiometric data are commonly recorded on strip charts or magnetic tapes.

LUMINESCENCE DIMENSION

Luminescence Imagery and Luminescence Detectors

Images showing the distribution of luminescing solids (various rock types) have been produced using active systems that illuminate the scene with ultraviolet light and record luminescence in the ultraviolet, visible, or infrared wavelengths; Figure 8 shows a quarry face near Baltimore, Md., as it appears in a conventional photograph and in images recording reflected ultraviolet light and ultraviolet-stimulated luminescence. Detectors that record ultraviolet-stimulated luminescence within Fraunhofer lines in the visible spectrum are being readied for flight test. These detectors have been used to detect luminescing substances in water in concentrations of three parts per billion. Laboratory tests suggest that some dolomites may be differentiated from limestones by observing their luminescence characteristics and that feldspars may be identified by measuring the decay time of ultraviolet-stimulated luminescence.

TIME DIMENSION

Time is probably the most powerful dimension within which to discriminate and identify objects or conditions. All sensors can be used to assess change in objects with time, provided their successive records can be efficiently compared.

Recognition of the value of repeated observations has led to proposals to place long-life sensors, such as television systems, in orbit. From orbit, repetitive images can

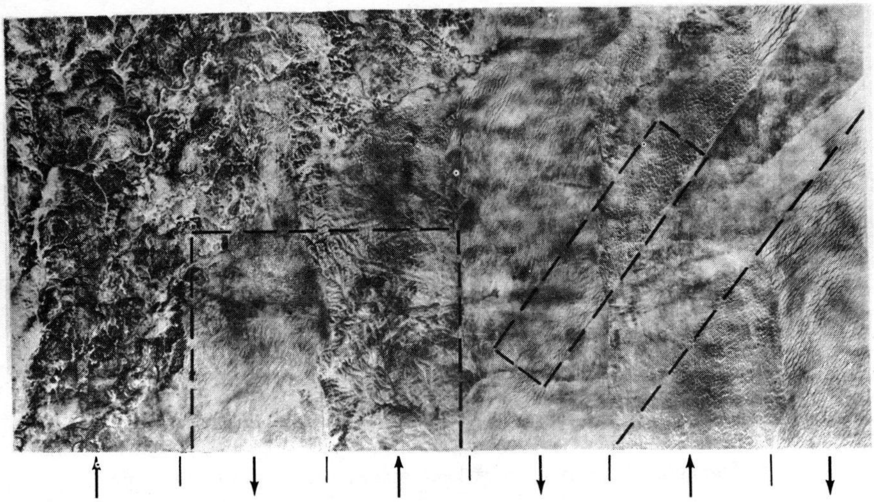


Figure 9. Mosaic of aerial photographs of part of the Arabian Peninsula; arrows show direction of flight; dashed lines outline areas of homogeneous terrain.

be obtained at relatively low cost. By using narrow-angle viewing systems, which can be economically employed from orbit, images may be acquired that are quite uniform and near-orthographic and hence may be easily compared for studying changes with time. Placing the satellite in sun-synchronous orbit so that repeated observations are made at the same local time also adds to the ease of comparing sequential images.

Intended to illustrate the significance of "controlling" time in studies relating to landform classification, Figure 9 is a carefully matched mosaic of aerial photographs of a part of the Arabian Peninsula. The directions of flight are indicated. There was approximately a three-hour difference in time between the northward and southward flights. All other flight and processing parameters, except time, were uniform. The outlined areas are homogeneous—the vast differences in appearance relate solely to changes in sun angle. From space, of course, all of this area and more would be visible from one point at one instant of time. Further, if the satellite were placed in sun-synchronous orbit, that is, an orbit where the earth/sun relationship stays constant, the entire earth can be viewed repeatedly at the same local time. Thus, successive observations would be easily comparable and changes with time readily assessable.

POLARIZATION DIMENSION

Comparison of radar images recording radar energy returns in two planes of polarization has resulted in improved discrimination of man-made objects from natural backgrounds and differentiation of rocks having differing surface roughness.

Studies of the polarization of sunlight and depolarization of "earth" (ashen) light reflected from the moon have aided in classifying elements of the lunar surface.

Laboratory and theoretical studies suggest that observations of polarization/depolarization, in all wavelengths, may evolve to useful techniques for classifying earth features, defining surface characteristics, and recognizing water pollutants.

SPATIAL DIMENSION

The development of the laser as a coherent source of light has made possible significant advances in optical processing techniques, including holography. These techniques

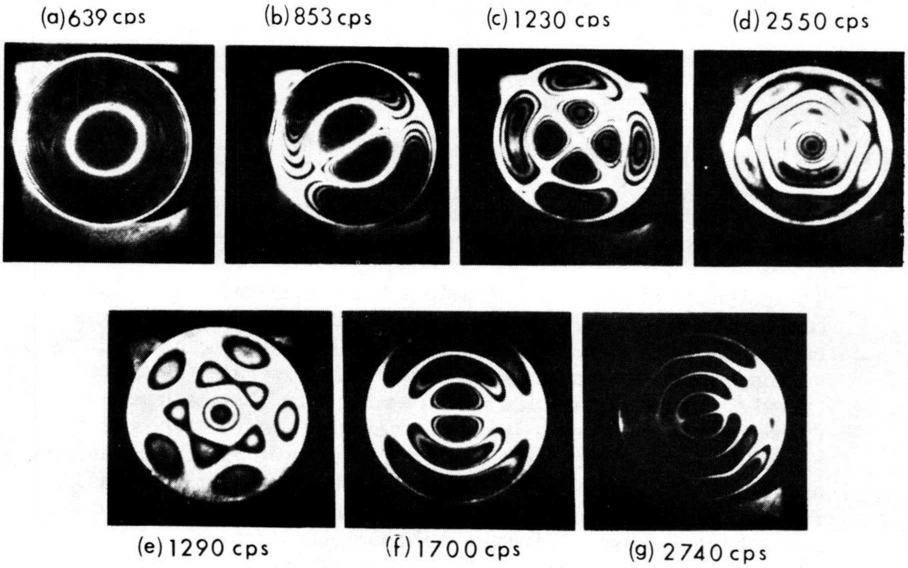


Figure 10. Hologram showing changes in patterns of vibration on the top of a tin can with changes in vibrational frequency (courtesy of Robert L. Powell, American Optical Company).

permit the emphasis of objects having orderly spatial arrangement and the measurement of change in positions, in terms of wavelengths of light. Several studies have been undertaken in which spatial filtering techniques have been applied to study of joint systems in rocks; to date, few evaluations of results have been published. Many illustrations of the value of holography as a mensuration tool, however, are published.

Figure 10 (Robert L. Powell, 1967) is a hologram showing the changes in vibrational patterns on the top of a tin can with changes in vibrational frequency. Holograms can provide the engineer and scientist with mensuration/interpretation data precise to wavelengths of light. In the opinion of the author, holography and related spatial filtering techniques are probably the most significant advances of recent years in the broad field of remote sensing. Although in their infancy, these techniques will soon provide to scientists and engineers an opportunity for quantum advances in their respective fields.

CONCLUSION

In summary, essentially all potentially usable parts of the electromagnetic spectrum are under investigation. Instruments are available to "sense" in most, if not all, of the spectrum, and in the various dimensions of remote sensing. Looking ahead, it seems likely that the increasing demands for resources and engineering data will accelerate the demand for timely survey data. This increasing demand for timely survey data will likely cause many of the current experimental systems to be placed in operational use in the near future.