Remote Sensing of Natural Resources

Several devices are now available to supplement the aerial camera in detecting natural resources from airplanes and spacecraft. They include radar, gamma ray detectors and sensors of infrared energy

by Robert N. Colwell

As pressures on natural resources increase, because of growing populations and rising standards of living, it becomes steadily more important to manage the available resources effectively. The task requires that accurate inventories of resources be periodically taken. Until as recently as a generation ago such inventories were made almost entirely on the ground. Geologists traveled widely in exploring for minerals; foresters and agronomists examined trees and crops at close hand in order to assess their condition; surveyors walked the countryside in the course of preparing the necessary maps. The advent of aerial photography represented a big step forward. Within the past few years the making of aerial photographs has been augmented by a new technique, in which sensing is done simultaneously in several bands of the electromagnetic spectrum. The name often given the technique is remote sensing. In its fullest form the technique ranges through the spectrum from the very short wavelengths at which gamma rays are emitted to the comparatively long wavelengths at which radar operates. In this way one can secure far more information about an area than can be obtained with conventional photography, which is limited to the visible-light portion of the spectrum.

Remote sensing can be done from aircraft or spacecraft, including unmanned satellites. It employs cameras and a number of other sensing devices. To some extent the data obtained by the sensing devices can be processed and interpreted automatically, so that a large volume of information can be dealt with rapidly.

The information thus obtained is useful to investigators in many disciplines. Geologists use remote sensing to find deposits of minerals and petroleum, to improve their understanding of the distribution and origin of major geological features and to study the exchanges of energy associated with such crustal disturbances as earthquakes and volcanic eruptions. Soil scientists can take inventory of the important physical and chemical characteristics of soils by relating these characteristics to the geological features and the types of vegetation found on images obtained by remote sensing. Foresters and agriculturists can determine what kinds of trees and plants are growing in an area, can assess the health of the forest or crop and can estimate harvests. Similar information can be obtained by workers interested in populations of livestock, wildlife and fish.

By means of remote sensing hydrologists can locate useful aquifers and can estimate the volume of surface and subsurface flow in watersheds. Oceanographers can map the movements of ocean currents, marine organisms and water pollutants. They can study in detail the daily and seasonal changes in tides, shorelines and the state of the sea. Geographers can analyze land-use patterns over broad areas and can study the interplay of climate, topography, plant life, animal life and human activity in a particular area. Engineers planning large construction projects such as highways, airports and dams can obtain data on landforms, rock materials, soils, types of vegetation and conditions of drainage. It goes almost without saying that remote sensing in various parts of the spectrum is invaluable to map makers in their efforts to identify ground features and to position them accurately.

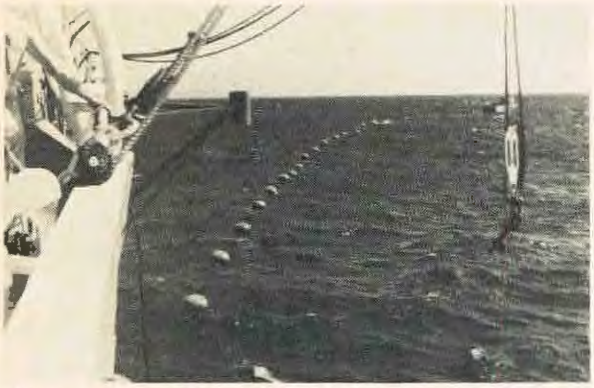
The earliest aerial photographs, made somewhat more than a century ago, suffered from the deficiencies of the cameras and emulsions and from the necessity of using such unsteady vehicles as balloons and kites for platforms. Today the array of equipment available for remote sensing can be matched to almost any requirement. Whatever the platform—helicopter, airplane or satellite—the camera can be mounted so that it is stabilized against roll, pitch and yaw and insulated against vibration. The aberrations of the lenses in cameras have been greatly reduced so that sharp images can usually be obtained. Roll film of high dimensional stability has almost entirely replaced emulsion-coated glass plates. Several kinds of color film are available to augment or replace black-and-white film in both the visible and the infrared portion of the spectrum.

Remote-sensing Equipment

Among the many types of equipment developed for remote sensing, six show the most value or promise for the inventory of natural resources. They are the conventional aerial camera, the panoramic camera, the multiband camera, the optical-mechanical scanner, side-looking airborne radar and the gamma ray spectrometer.

A conventional aerial camera has four basic components: a magazine, a drive mechanism, a cone and a lens [*see top illustration on page 58*]. The magazine

CENTRAL AUSTRALIA'S characteristic topography appears in the photograph on the opposite page, made from the *Gemini V* spacecraft on August 27, 1965. The spacecraft was at an altitude of 165 miles; the area shown is west of Alice Springs. An experienced interpreter can use such a photograph to obtain information about a variety of natural resources and land uses. Some ways the photograph can be interpreted are illustrated on pages 56 and 57.



With sound under 10,000 ft. of water. Mooring buoys go overboard to help position a giant-size Bendix transducer above the ocean floor, almost 2 miles down. It will receive or respond to signals for research in acoustic navigation.

With a finished part in 36 sec. It's typical of the way Crushtrue® grinders reduce machining time on metal parts. And Bendix abrasive machining methods eliminate preforming operations and the need for finish grinding—with one plunge of the wheel.

Photo: Northrop Corporation

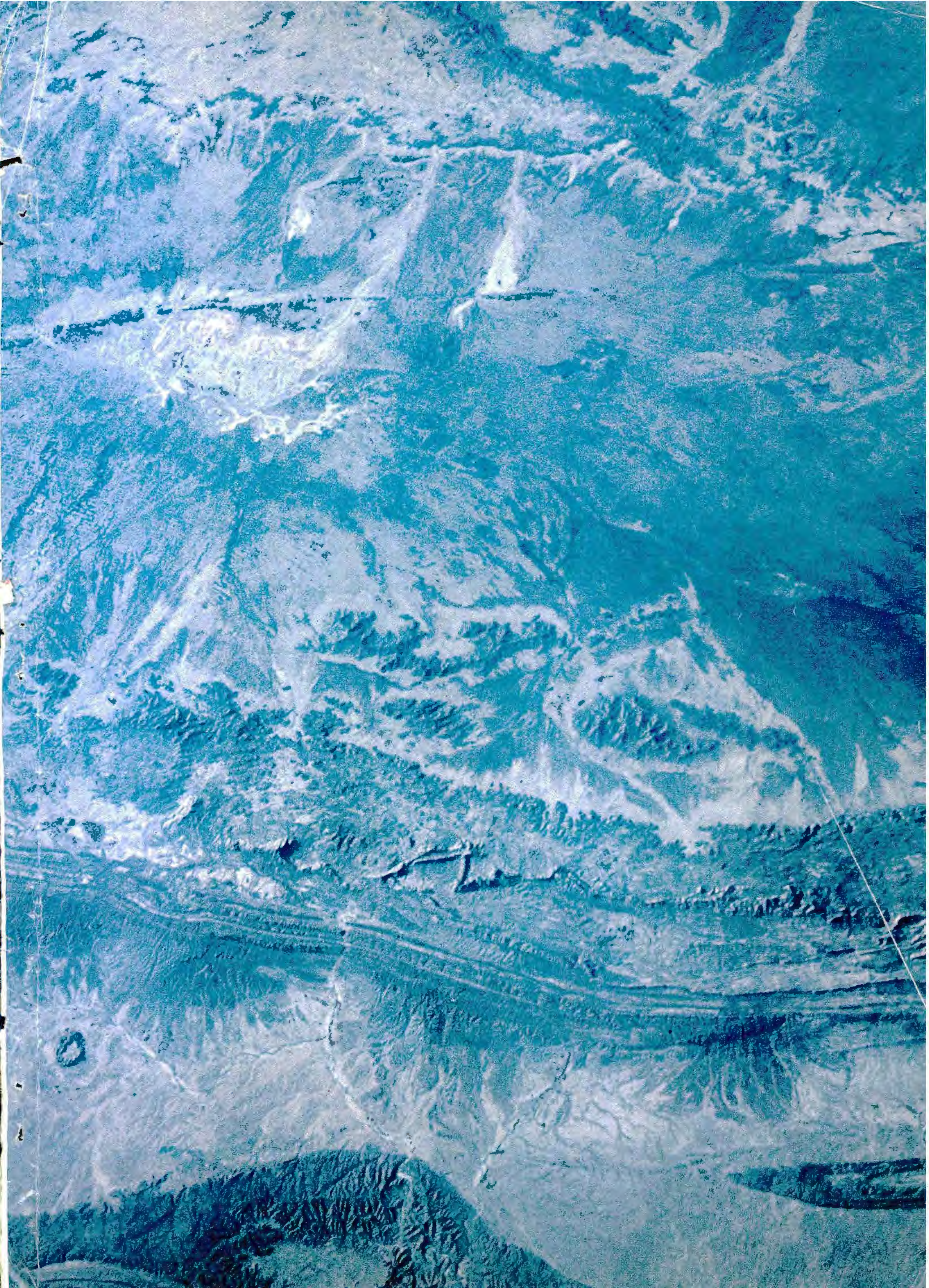
With automatic altitude reporting. New Bendix airborne computer systems help close the information gap in air traffic control. They instantly correct for errors in measured pressure and provide the correct altitude data for the pilot and ground control.

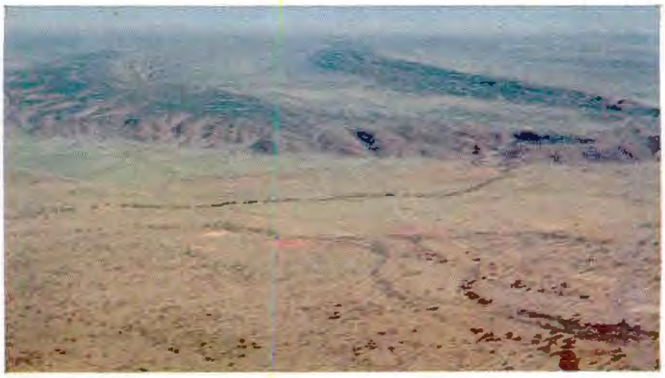
With full power hydraulic braking. This Bendix advancement, 10 years in development, gives trucks a complete dual brake system. It retains front-wheel hydraulic pressure if there's a failure in the circuit to the rear—and vice versa. Other advantages over present systems include faster response time, reduced driver fatigue and less maintenance.

With circuits that can run on air. Bendix is a pioneer in fluidics, the new technology in which gases and liquids are forced through channels to perform electronic-like functions. More and more sophisticated fluidic circuits, like this art master 50 times actual size being checked by a Bendix technician, are being developed for cars, machine tools, power plants, aircraft and other applications. They're tough, reliable, maintenance-free, spark-free and inexpensive when mass-produced from low-cost materials. Today Bendix is making fluidic systems so rugged you can heat them to 1,200°F.—so small you can hold them in your hand. The technology is new. Our role in it isn't. The heart of our business is creating ideas and developing them to maximum usefulness—whether we're serving as manufacturers, creative engineers or professional problem-solvers for industry and government. The Bendix Corporation / Fisher Bldg. / Detroit, Michigan 48202.

Bendix

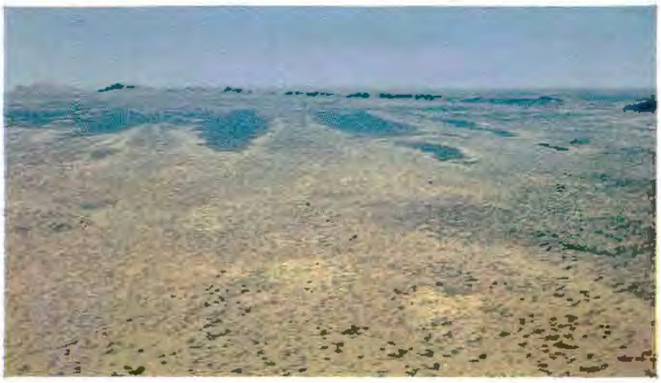
Where ideas unlock the future



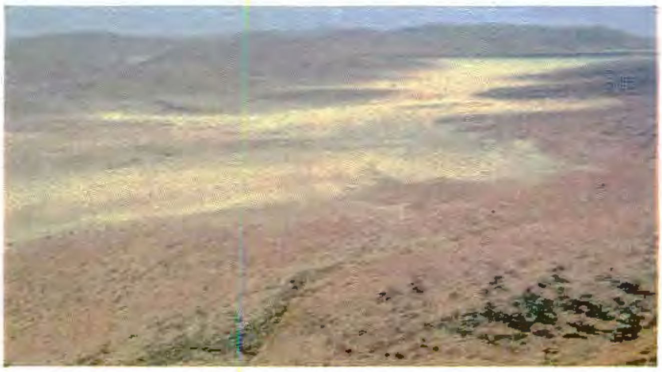


MAIN FEATURES of the *Gemini* photograph (*see key on opposite page*) include two geological formations indicative of sedimentary rocks. *A*, at left, shows steeply dipping beds in the MacDonnell Range; *B*, at right, shows eroded rocks in the Waterhouse Range.

FURTHER INTERPRETATION of the *Gemini* photograph led to the conclusion that *C*, known as Gosse's Bluff, is a meteorite crater (*left*). The region marked *D* on the spacecraft photograph and shown at right above has several features that indicate alluvial soil.



SOIL RESOURCES ascertained from study of the *Gemini* photograph include *E*, shown in a low-angle view at left; dunelike patterns suggest a sandy soil. *F*, at right, is a dry lake bed; there the interpreter would predict the existence of heavy clay soils.



VEGETATION BOUNDARIES appear more distinctly in the *Gemini* photograph than in low-angle views. *G*, at left, is a boundary between mulga, a type of acacia tree, and spinifex, a grass. *H*, at right, is a boundary between Mitchell grass (*yellow*) and spinifex.

is the light-tight box that holds the film. Usually it can be detached from the rest of the camera. The film is ordinarily in the form of a continuous roll 9½ inches wide and 200 feet long. Such a roll will accommodate about 250 exposures, each nine inches square.

The drive mechanism is a series of cams, gears and shafts designed to move the film from the supply spool to the take-up spool. As the film moves, rollers guide it over the front surface of a locating plate. One of the rollers is designed to meter the amount of film passing from the supply spool to the take-up spool between exposures, thereby providing a correct and uniform spacing of exposures on the roll of film.

During an exposure, suction is created behind the locating plate by means of a venturi tube or a special vacuum-cylinder-and-piston apparatus built into the magazine. The suction, transmitted to the film through small perforations and grooves in the locating plate, holds the film in a flat plane against the locating plate at the instant of exposure. In this way distortions that would be caused by wrinkles in the film at the moment of exposure are minimized.

The cone is a light-tight unit that holds the lens in the correct relation to the film. The length of the cone is governed by the focal length of the lens, which is essentially the distance from the center of the lens to the film. It is not unusual for a magazine to have interchangeable cones to accommodate lenses of differing focal lengths. Most of the aerial photography done for the inventory of natural resources uses focal lengths of six, 8¼ or 12 inches.

The lens is a compound one that is carefully designed to cast an undistorted image on the large area of the film. Aerial cameras usually have fixed-focus lenses with the focus at infinity; the camera is used so far above the ground that such a focus will provide a sharp image of all objects on the ground. In most aerial cameras the shutter is between the front and the rear elements of the lens. The drive mechanism of the camera recocks the shutter automatically after an exposure.

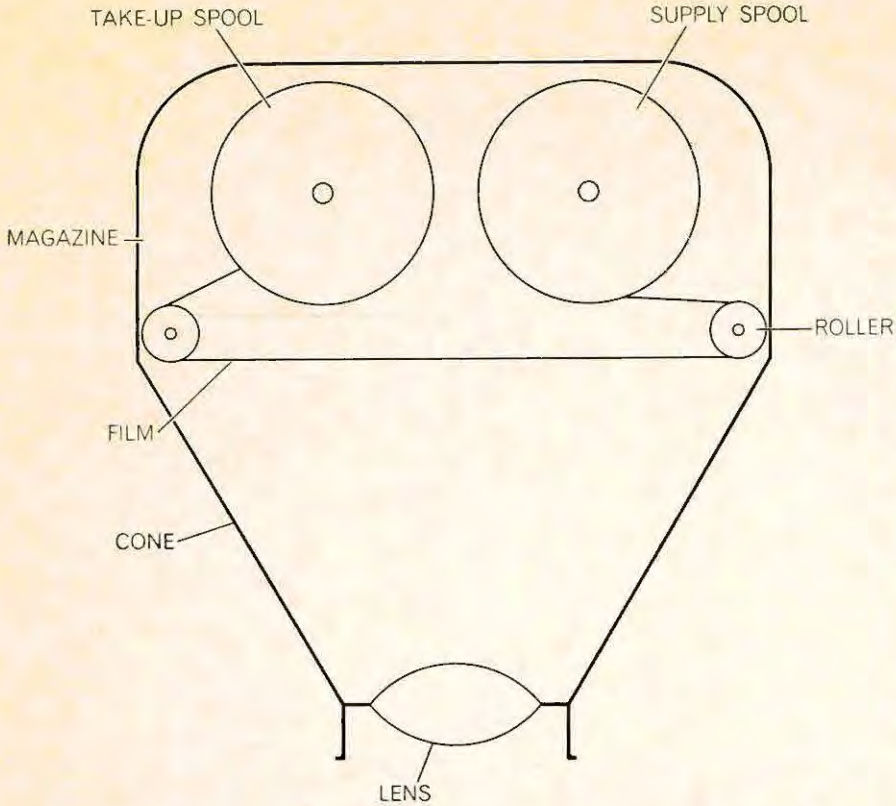
The panoramic camera [*see bottom illustration on next page*] makes it possible to photograph a large area in a single exposure at very high resolution, meaning with a high degree of sharpness of image in every part of the photograph. The camera meets a need but creates some special problems. In order to get a sharp image when photographing large areas, one paradoxically needs a narrow angular field so as to minimize aberrations of the lens. Such a field is provided in the panoramic camera by a narrow slit in an opaque partition near the focal plane of the camera. The slit is parallel to the camera platform's line of flight. With such a slit, however, one will be able to photograph only a narrow swath of terrain unless the optical train of the camera is equipped to pan, or move from side to side, as the aircraft advances. The optical train of the panoramic camera is designed to make such movements.

On the other hand, for the panoramic camera to maintain a uniformly clear focus as the optical train moves, the frame of film being exposed must be held in the form of an arc instead of being kept flat as in a conventional camera. With the film in an arc the photographic scale becomes progressively smaller as the distance of objects on the ground increases to the left and right of the flight path. In some applications the scale problems outweigh the advantage of a panoramic field of view, so that it is preferable to use a conventional camera.

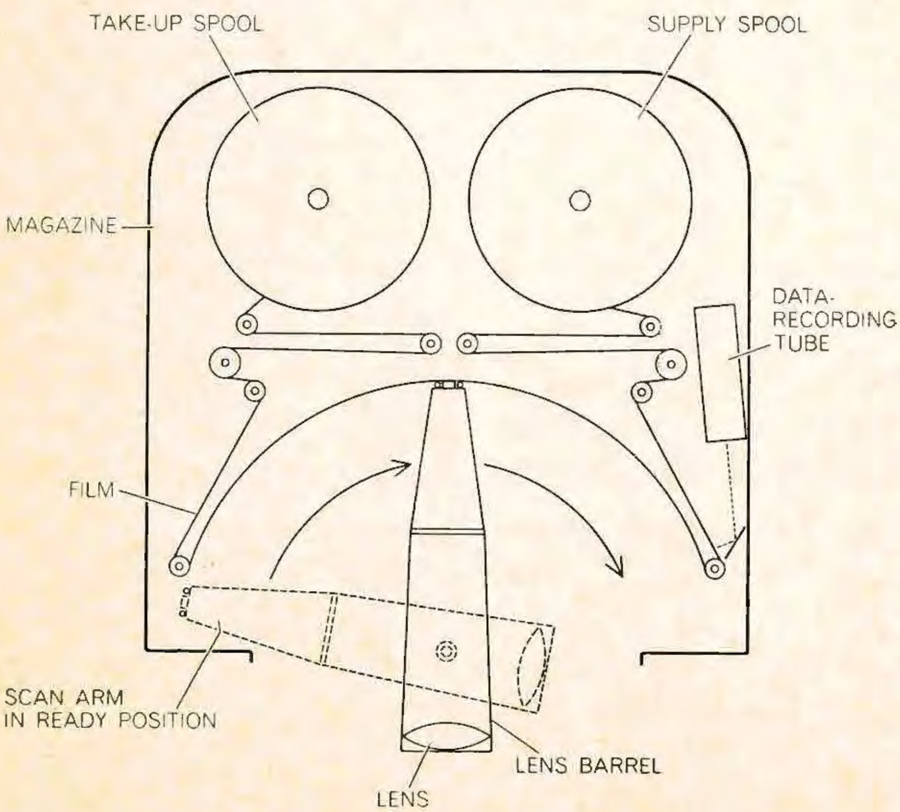
Related Devices

The multiband camera makes photographs simultaneously in several bands of the spectrum. In essence it provides a variety of lens, filter and film combinations, each designed to obtain maximum information from a particular band. A typical camera might have nine such combinations [*see illustrations on page 59*]. Together the lenses give the camera a capacity to sense in the range of

PRINCIPAL FEATURES of the *Gemini* photograph on page 55 are identified. The arrows show direction in which the low-angle aerial photographs on the opposite page were made.



CONVENTIONAL AERIAL CAMERA uses film in roll form and can make about 250 exposures, each nine inches square. Magazine holds the film. Cone positions lens with respect to the film, at a distance governed by the focal length of the lens. Film being exposed is held flat against a locating plate to minimize distortions and provide uniformly sharp images.



PANORAMIC CAMERA was developed to provide sharp aerial photographs of large scale. Since the camera must have a long focal length it must also have a narrow angular field. As a result it requires a scanning mechanism that moves the lens barrel to left and right. At any instant during the course of a scan only light passing through a narrow slit falls on the film.

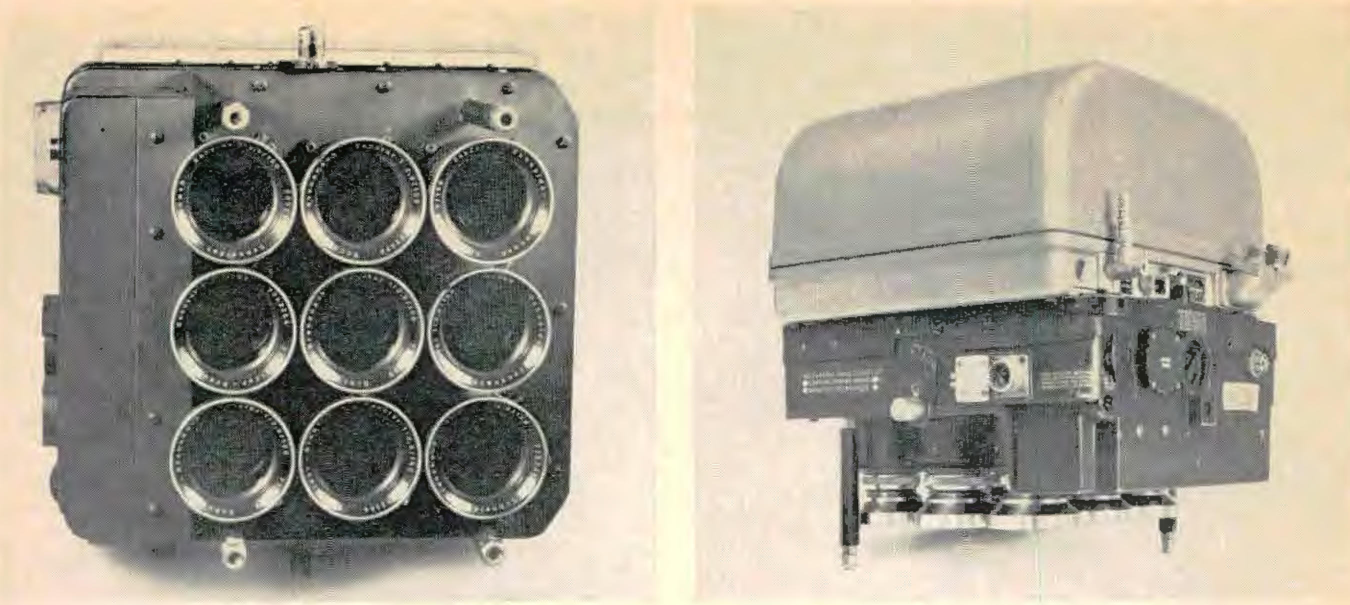
wavelengths from .4 to .9 micron, which is to say throughout the visible spectrum and into the very near infrared. All nine shutters click simultaneously, thus yielding nine photographs, each with tonal values that are distinctive for its portion of the spectrum. Study of distinctive tonal values in nine photographs of an area enables the interpreter to determine a "tone signature" for each type of object. As a result he obtains much more information about the area's natural resources than he could obtain from any one of the photographs.

The optical-mechanical scanner meets the need for a device that will sense farther in the infrared—in what is commonly called the thermal infrared region. Ordinary photographic film is not sensitive to wavelengths in the thermal infrared region. It would be possible to coat a film with a material sensitive to such wavelengths, but then the problem would arise of protecting the film from the thermal energy being emitted by the camera. Just as the conventional camera must be a light-tight box to keep light-sensitive film from fogging, so a thermal infrared camera would have to have a heat-tight box to keep heat-sensitive film from fogging. In fact, the box would have to be continuously cooled almost to absolute zero, which is a practical impossibility for a large airborne sensing device.

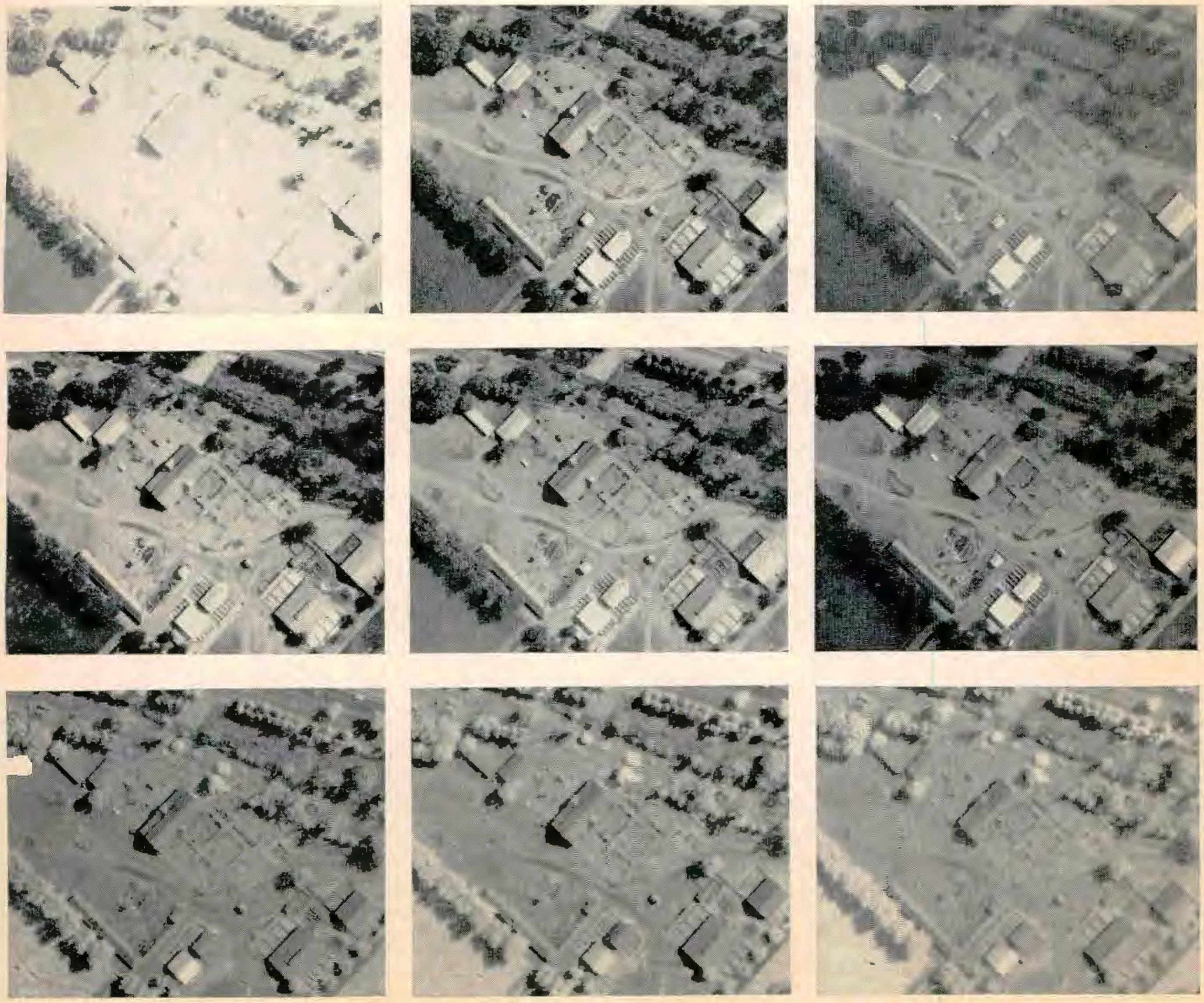
Thus a "camera" that translates thermal energy directly onto film is out of the question. It is possible, however, to obtain photographic images of thermal energy indirectly, and that is what the optical-mechanical scanner does. The device uses a detector that consists of a coating of some infrared-sensitive material such as copper-doped or gold-doped germanium on the end of an electrical conductor. The material occupies an area no bigger than a pinhead. It is entirely feasible, even in an airborne system, to cool this small detector with liquid nitrogen for sensing at wavelengths of from three to six microns and with liquid helium for longer wavelengths.

A rotating mirror directs to the detector energy emanating from the terrain. At any instant the mirror views only a small segment of terrain. Infrared photons striking the detector generate an electrical signal that varies in intensity according to the amount of thermal energy coming from the part of the terrain then being viewed by the mirror. The signal, by being converted to a beam of electrons, can generate visible light, such as the moving luminous spot on the face of a cathode-ray tube. The spot grows brighter or dimmer in direct

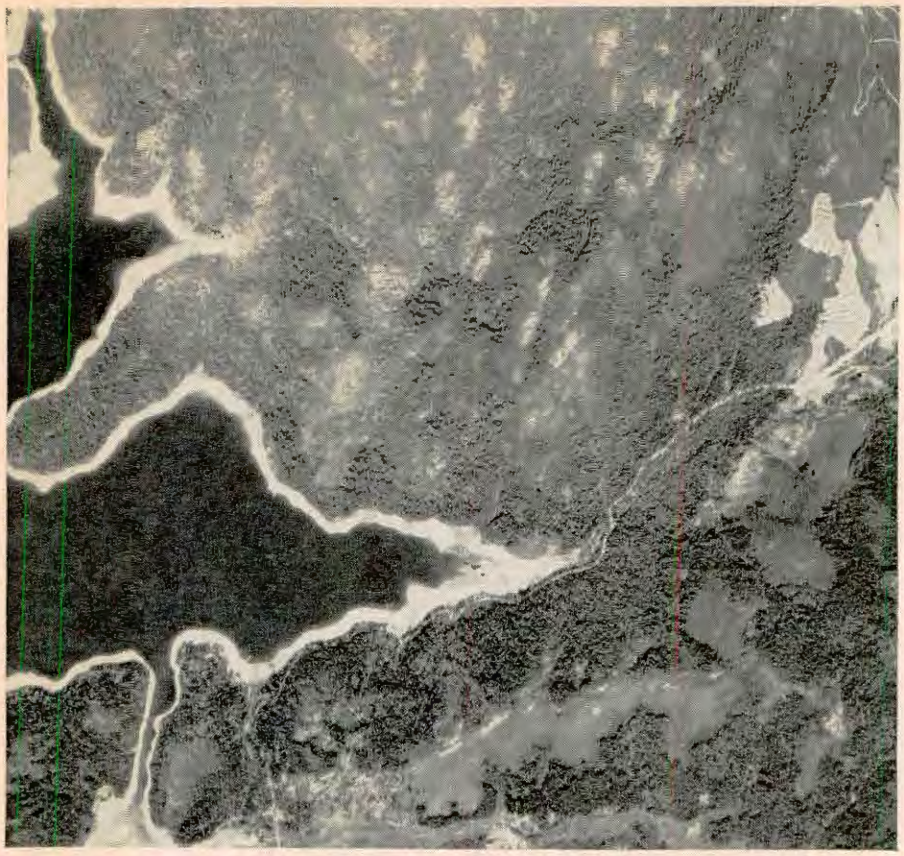
scuro



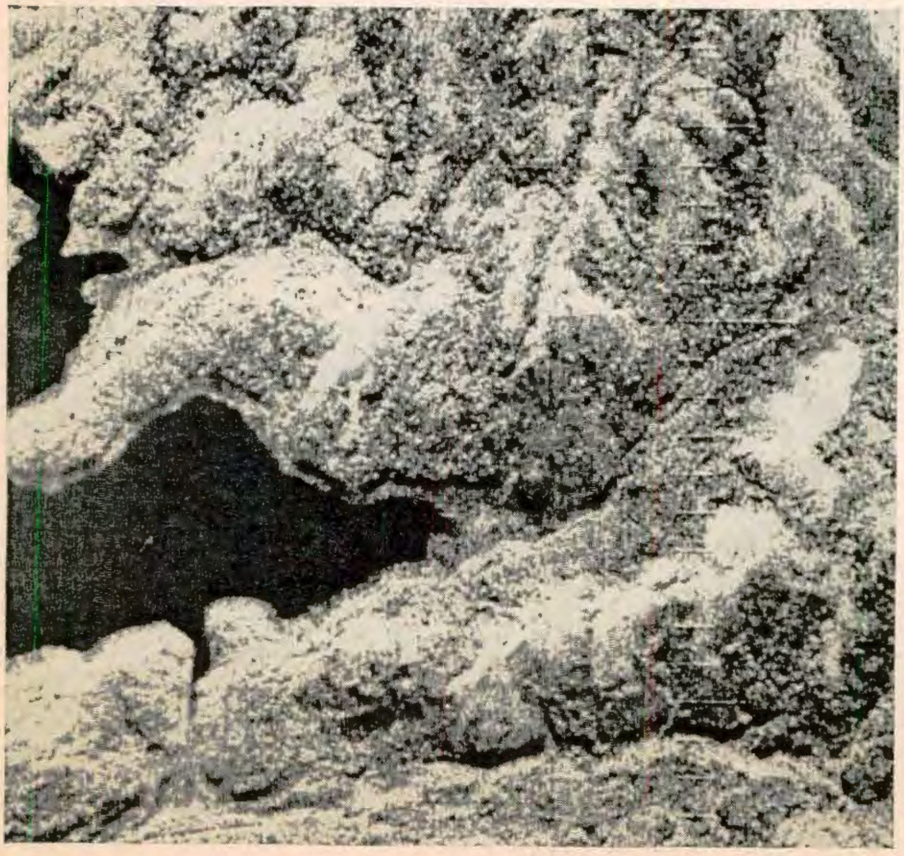
MULTIBAND CAMERA has nine lenses and nine film-filter combinations, each designed to function best in one part of the spectrum. Camera permits more positive identifications to be made of certain natural resources from their multiband "tone signatures."



MULTIBAND EXPOSURE was made with a multiband camera. The wavelengths of energy represented range from .38 micron (*top left*) to .9 micron (*bottom right*), which covers not only the visible spectrum but also parts of the ultraviolet and near-infrared regions.



PANCHROMATIC VIEW of the Bucks Lake area of the Sierra Nevada was obtained with panchromatic film, meaning film that is sensitive to the entire visible spectrum. Such a photograph is particularly useful for estimating the density of vegetation and for identifying certain species of vegetation. The area is part of the one shown in color on page 63.



RADAR VIEW of the same area is especially useful for discerning types of vegetation that appear less clearly in panchromatic view. Radar also shows drainage networks more clearly.

proportion to the strength of the electron beam. An image of the light is recorded on photographic film, and the analyst obtains what is in effect a thermal map of the ground.

The scanner is not limited to sensing in the thermal infrared region of the spectrum. It can provide multiband imagery in any band from the near ultraviolet through the visible and photographic infrared regions and into the thermal infrared. Moreover, in "photographs" made by the instrument the general shape of ground features is essentially the same in every band, so that the images can be superposed or otherwise compared readily.

Side-looking airborne radar, commonly called SLAR, brings to remote sensing such valuable attributes as all-weather and around-the-clock usefulness and the ability to penetrate a cover of vegetation. Because radar operates at much longer wavelengths than the other equipment I have described, however, it does present difficulties in obtaining high resolution. Recent developments such as SLAR equipped with a synthetic aperture system have brought about large improvements in the quality of radar imagery.

In the SLAR system a transmitting antenna in the airplane sends a short pulse of microwave energy out one side of the plane. The energy strikes a roughly circular area on the ground, and a receiving antenna collects the energy reflected back to the plane. The greater the distance from the aircraft to any portion of the target, the greater the time delay in the return of the reflected signal. By accurately measuring the time delay, SLAR differentiates the echoes that return to it from various small concentric rings. Each ring represents the locus of all points within the large circle that are roughly equidistant from the plane.

Within any ring there is a spot just opposite the aircraft that moves along at the same speed as the aircraft. At any given time the distance from the aircraft to all other points on the ring is either increasing or decreasing. Here the Doppler effect comes into play: the frequency of the reflected signal changes according to whether the plane is approaching a given point or receding from it. As a result the microwave energy reflected back to the aircraft from such points differs in frequency from the energy transmitted to them. The radar receiver is designed to accept energy of approximately the same frequency as the initial pulse and to reject significantly different frequencies.

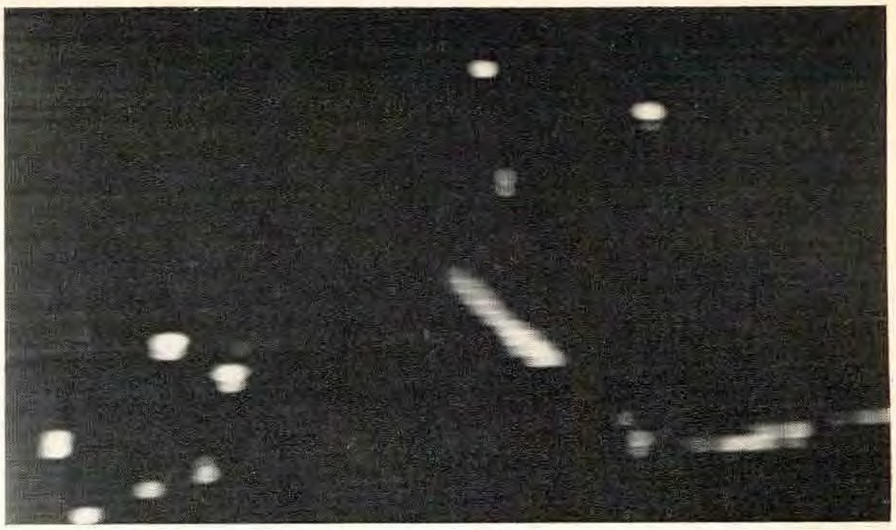
Because of the two discriminating effects—one depending on time delay and the other on the Doppler effect—the radar receiver accepts at any given instant only the energy that meets two conditions: that it be from the narrow ring within which the time delay is such that the energy is at that instant striking the receiving antenna, and that it be in the particular part of the ring that is directly opposite the aircraft—the part having almost no relative velocity with respect to the aircraft and thus exhibiting no Doppler effect. Together the two discriminating features provide the synthetic aperture. The technique greatly improves the spatial resolution of the system.

Radar images are transformed into photographic images in the same way that photographic images are produced by the optical-mechanical scanner. The microwave energy is converted to an electron beam that operates a cathode-ray tube, and the light is recorded on film. The density on each portion of exposed film is in proportion to the brightness of the radar signal coming from the corresponding spot on the terrain.

The gamma ray spectrometer functions at very short wavelengths—a millionth of a micron or less, compared with the billion microns or more at which radar and other microwave sensors operate. The spectrometer is excellent for locating radioactive substances, even when it is operated at altitudes of several thousand feet above the ground. It is therefore useful in prospecting for minerals. Moreover, a gamma ray spectrometer can be designed to operate in as many as 400 different channels, or wavelength bands, so that the instrument has considerable ability to differentiate each of several radioactive minerals.

Analysis of Data

Remote sensing of natural resources rests on the fact that every feature of the terrain emits or reflects electromagnetic energy at specific and distinctive wavelengths. The analyst cannot hope to accomplish much in the way of interpreting the data, however, until he takes the time to determine what spectral response pattern—what multiband tone signature—to expect from a given feature. The best means of accomplishing this is to set up a test site in which each type of feature that is to be identified by remote sensing is exhibited. By studying multiband images obtained from the test site the analyst will equip himself to recognize, by their unique spectral response patterns, the features that are of interest to him in a sensing mission. Ideally at least one such test site should be includ-

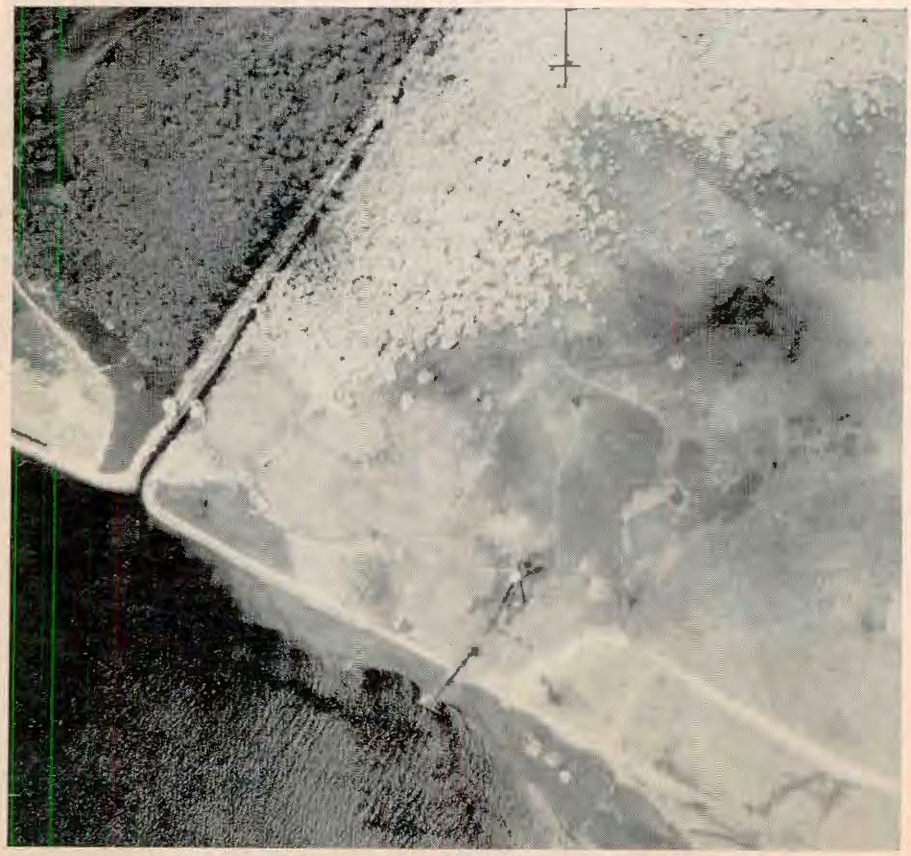


THERMAL INFRARED image of a site in Yosemite Valley shows several campfires better than sensing in other bands would. Thermograph, which senses infrared wavelengths and uses them to govern a source of visible light that is recorded on film, was about a mile above the valley. Smallest fire detected was one charcoal briquette less than a cubic inch in size.

ADDITIONAL VIEW of the Yosemite Valley site from the same station was made with the thermograph set to function at wavelengths of eight to 14 microns and so brought out vegetation in meadows (*right*). The fire-sensing thermograph functioned at three to five microns.

TIMBER RESOURCES stand out in this thermal infrared view of same site. Thermograph was set for eight to 14 microns but the image was obtained by day rather than by night.

MANGROVE TREES in a swamp near Brisbane, Australia, appear normal in this panchromatic aerial photograph. Sensing in another part of the spectrum told a different story.



INFRARED VIEW of the same mangroves shows that the trees at upper left have been damaged. Mud had been pumped into the basin. Unhealthy trees and crops have a dark tone in infrared because of a previsual loss in reflectance at infrared wavelengths of .7 to .9 micron.

ed in each sensing flight for calibration purposes.

Eventually it may become possible to identify every feature in a given area. The technique of sensing in a variety of wavelengths promises to speed progress toward that objective. As the number of spectral bands used in remote sensing is increased, the identifying response pattern for each natural resource becomes more complete and more reliable.

At the same time the increase in spectral bands sensed means that the task of analyzing data grows larger. It can become unmanageable unless the analyst has equipment that helps him to correlate the multiband images. The problem is that he confronts several black-and-white images, each with distinctive tone values for particular features. He can find himself in confusion if he interprets one image, goes on to another, refers back to the first and so on for a number of images.

One way to deal with the problem is to reconstitute the various multispectral black-and-white images into a single, composite color image. The usual technique is to project each black-and-white image through a colored filter. A battery of projectors is used so that all the images can be superposed simultaneously on the screen.

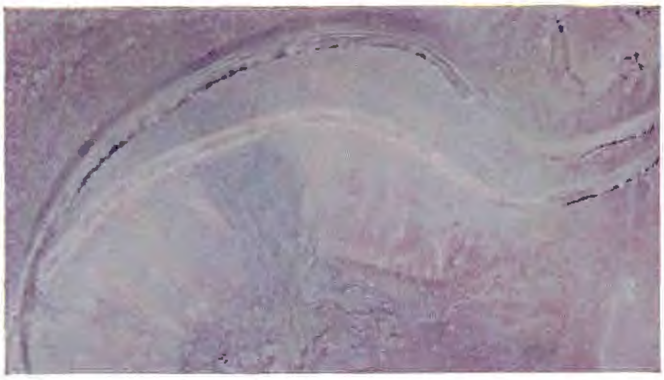
In such a composite image the tone or brightness of a ground feature as recorded in any given spectral band is used to govern the intensity of one of the colors used in the composite. By varying the selection of colored filters the analyst can change the color contrast of the composite. Often by this means he finds that one combination of filters provides the best interpretability of one kind of feature, whereas other filters provide better interpretability of other features. The bottom two illustrations on page 64 are composites made in this way.

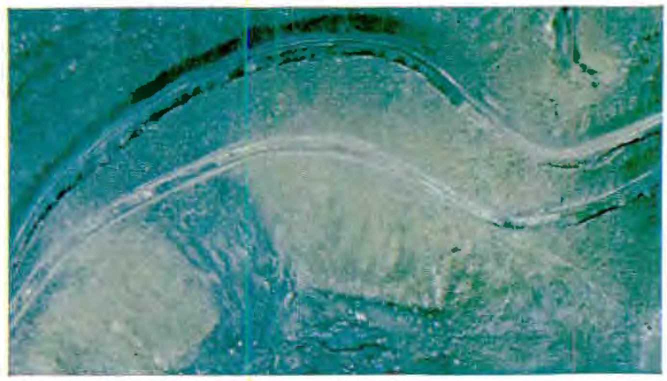
A second way of correlating multiband images is to use a battery of photoelectric sensors to scan all the black-and-white images simultaneously. The sensors record degrees of brightness. For each spot scanned the sensors automatically determine a tone signature, which in theory will be identifiable with some signature established from the test site. By this means the analyst can identify what features the remote-sensing equipment detected on the ground.

In its ultimate form the technique will result in a tape printout indicating the objects and conditions encountered at every spot in the multiband imagery. The method has not been developed to that stage, but even at its present stage of development it is able to provide

WILD-LAND RESOURCES are studied in a test area in the Bucks Lake region of the Sierra Nevada. This photograph was made from a camera station on a rock 2,000 feet above the lake. The station is used to make simulated aerial photographs of a known area. Such terrestrial photographs can be used as guides in interpreting similar photographs, obtained from aircraft or spacecraft, of regions where the wild-land resources need to be identified. A normal color photograph is only one of several types of photograph used for evaluating resources. Sensings can also be made in other wavelength bands of the spectrum to detect different physical features.

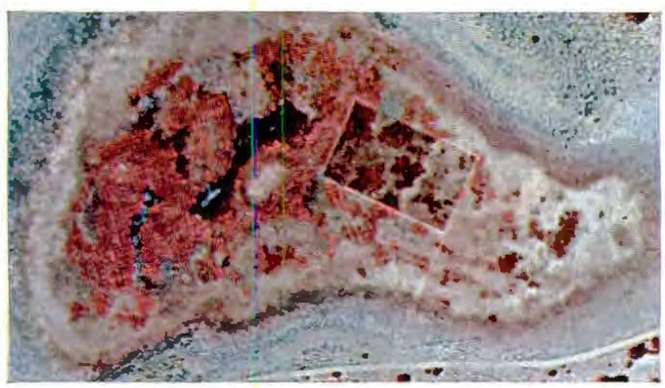
SAME AREA of the Sierra Nevada is photographed in infrared. The film used to make both this photograph and the one on the cover of this issue contains a red dye that is sensitive to near-infrared wavelengths of .7 to .9 micron. The false colors often provide more scope for interpretation than is possible with other film. Largest amounts of infrared energy produce the reddest color.



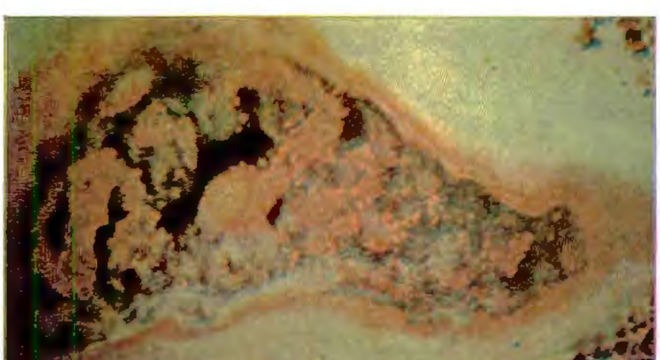


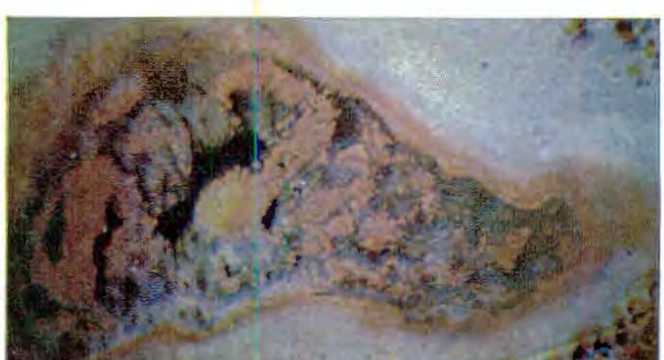
ROCK TYPES are differentiated more clearly in an infrared photograph (*right*) than in a full-color photograph (*left*) of the same area. The technique may aid in identifying rocks on moon that contain hydrated salts and could be a source of water for astronauts.

LIVESTOCK can often be identified more precisely in an infrared photograph than in normal color. Here the same group of livestock is photographed in normal color (*left*) and in infrared (*right*). Test panels appear at the left and right sides of the photograph.



RANGELANDS merit study in both normal color and infrared photography. Two types of forage, bitterbrush and big sage, appear more clearly in infrared photograph at right than in the normal-color photograph at left. Bitterbrush is bright red; sage, dark.





SAME AREA of rangeland is shown in a multiband technique. Black-and-white pictures, exposed at various wavelength bands, are projected separately with filters of different colors; the projections are combined in single images that bring out significant features.

enough automatic analysis of images to reduce considerably the amount of work done by the analyst. The illustrations at right show the results of photoelectric scanning of an aerial photograph.

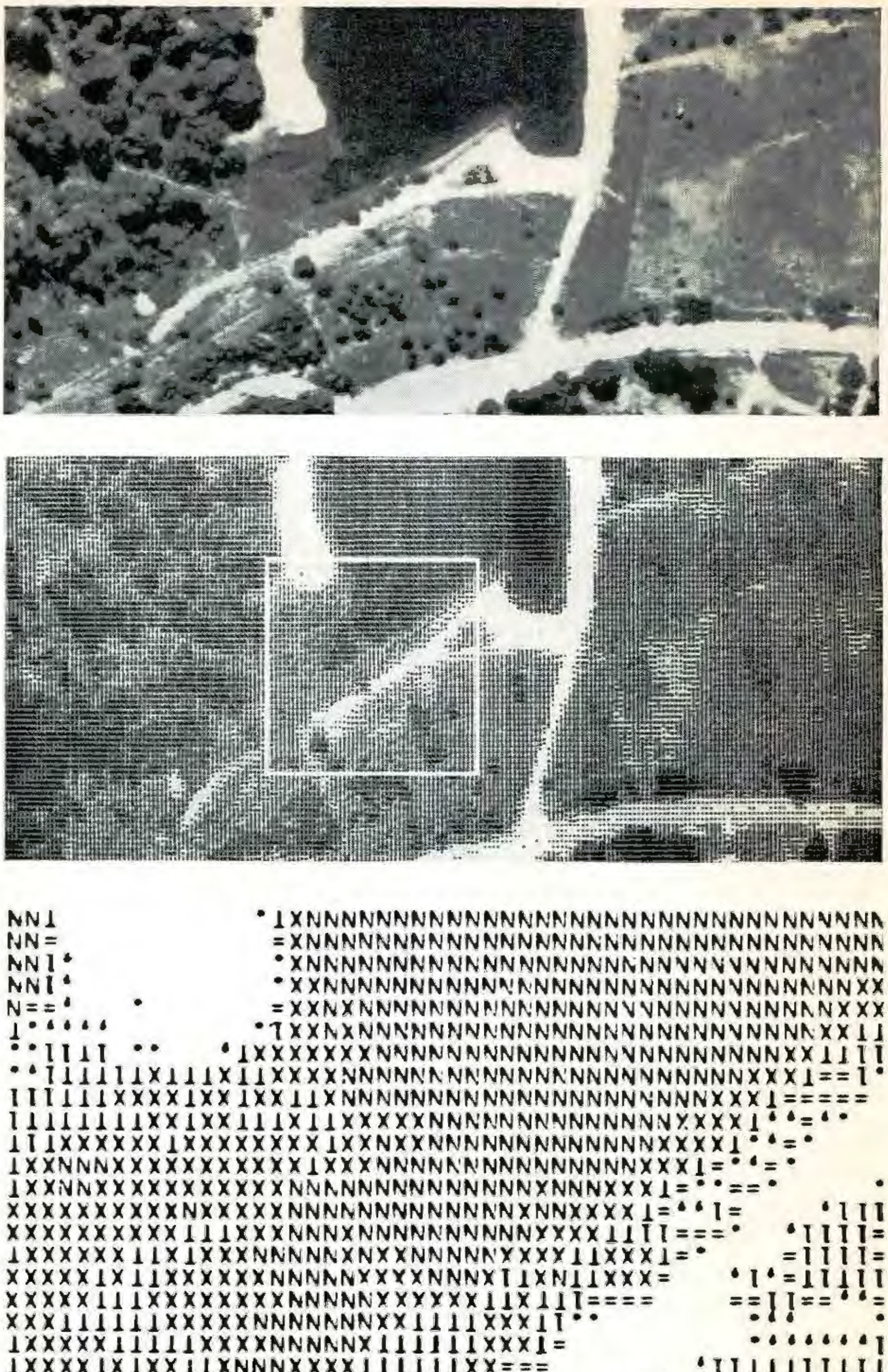
In a third technique the multiband sensing system records on magnetic tape, rather than on photographic film, the signal strength from each object in each spectral band. Thereafter the procedure is essentially the same as it is in the photoelectric scanning technique. The third method provides a complete inventory only moments after the remote sensors have been flown over the areas of interest. It also makes possible an analysis of the signal strengths emanating directly from the sensed objects, whereas in the second method the analysis is of signals that may have been degraded in the process of forming multiband images of the objects.

Some Applications

Against the background of sensing equipment and analytical techniques that I have described it is possible to consider in more detail some of the ways in which remote sensing can contribute to the management of natural resources. Several of the possibilities are illustrated in the photograph on page 55, which was made from the spacecraft *Gemini V* and shows a large area of central Australia. The principal features of the area are identified by letters in the black-and-white reproduction of the photograph on page 57.

The southern part of the MacDonnell Range [*A in the photograph on page 57*] has steeply dipping parallel beds that the geologist would recognize as indicating the presence of folded sedimentary rocks varying in hardness and in susceptibility to erosion. The characteristics of the northern part of the range would suggest to the geologist that the rocks there are igneous or metamorphic. Evidence of faulting appears in the linear ridge that runs through the northern part of the range. The characteristics of the Waterhouse Range [*B in the illustration*] suggest sedimentary rocks that long ago were folded into an anticline, or upfolded structure, and have since been eroded to varying degrees. Careful study of shadow detail in the vicinity of the circular structure known as Gosse's Bluff [*C*] reveals that it is a hollow outcropping of rocks that probably resulted from the impact of a large meteorite.

From even this crude interpretation of the photograph a mineralogical prospector would be able to deduce that some of the best prospects for metallic



AUTOMATIC ANALYSIS of tonal qualities can be done with a photoelectric scanner. At top is a photograph made with a multiband camera. At center is a scanner's print in which "N" shows darkest tones and other symbols represent lighter tones. At bottom is an enlargement of the outlined area. Since each natural resource tends to have a unique multiband tone signature, automatic encoding of tones may lead to automatic resource inventories.

minerals are to be found along the discernible fault lines in the MacDonnell Range. The petroleum geologist would be interested in the folded anticline of the Waterhouse Range. It is equally significant that the searchers for both metals and petroleum often can eliminate nearly 90 percent of the vast area shown in a small-scale photograph as being unworthy of detailed mineralogical or petroleum surveys. Important deposits of either kind are rarely found in areas that photographically show little geologic evidence of their presence.

The *Gemini* photograph is also helpful in assessing the soil resources of the area. For example, it can be assumed that most of the central region [*D*] has deep alluvial soils because there are nearby mountain ranges from which alluvial deposits are likely to have come, because the pattern of streams indicates that a considerable amount of outwashing activity has taken place even though the area now seems arid, and because in the outwash plains geologic features have become so deeply buried, presumably by deposited soil, as to be indiscernible. In the top left portion of the photograph [*E*] the presence of sandy soil is suggested by the dunelike patterns, which continue appreciably beyond the edge of the photograph. A dry lake bed [*F*] is likely to contain heavy clay soils.

The photograph is of further usefulness in determining the vegetational resources of the area. Even though the photographic scale is small, several vegetational boundaries can be seen. One of considerable significance [*H*] shows two types of grass: Mitchell grass on the left and spinifex on the right. Areas of Mitchell grass are far better than other grassland for maintaining livestock. Moreover, they normally are indicative of the most fertile soils in an area, a point of great importance if the objective is to find new land to put to the plow.

In mapping vegetational boundaries the lack of fine detail in a photograph such as the *Gemini* one may actually be helpful. The fact is evident if one looks at the area marked *G* in the *Gemini* photograph and at the corresponding oblique aerial photograph at the bottom left on page 56. The boundary is between mulga (a type of acacia tree) and spinifex. In the *Gemini* photograph the boundary is clear; in the oblique photograph it is difficult to follow even though more detail is discernible there.

Recently I accompanied Ray Perry of the Commonwealth Scientific and Industrial Research Organization in a check of the ground shown in the *Gemini* photograph. We made the oblique aerial photographs that appear on page 56. The check showed that the interpretations

SALTON SEA AREA of southern California appears in a photograph made from a Gemini spacecraft. The pattern is made by farmland. Individual fields as small as 40 acres can be distinguished. Many kinds of farm crops can be identified in such a photograph.

previously made from the *Gemini* photograph were correct in all respects.

I have dwelt at length on this single *Gemini* photograph in order to suggest the capabilities of spacecraft photography in the remote sensing of natural resources. Since the whole of an area as big as Australia can be depicted in a short time with a few photographs from a spacecraft, the possibilities of the technique are enormous, particularly for the vast areas of the world that are yet to be developed. Australia is a case in point. According to Australian scientists, virtually all the significant geologic, soil and vegetational features found in approximately 70 percent of the continent's arid regions are represented in the *Gemini* photograph that I have described. It seems evident that one of the best ways to produce suitable reconnaissance maps for the remainder of underdeveloped Australia and for other underdeveloped areas of the world would be through the use of space photography, supplemented as necessary with large-scale aerial photographs and with field checks.

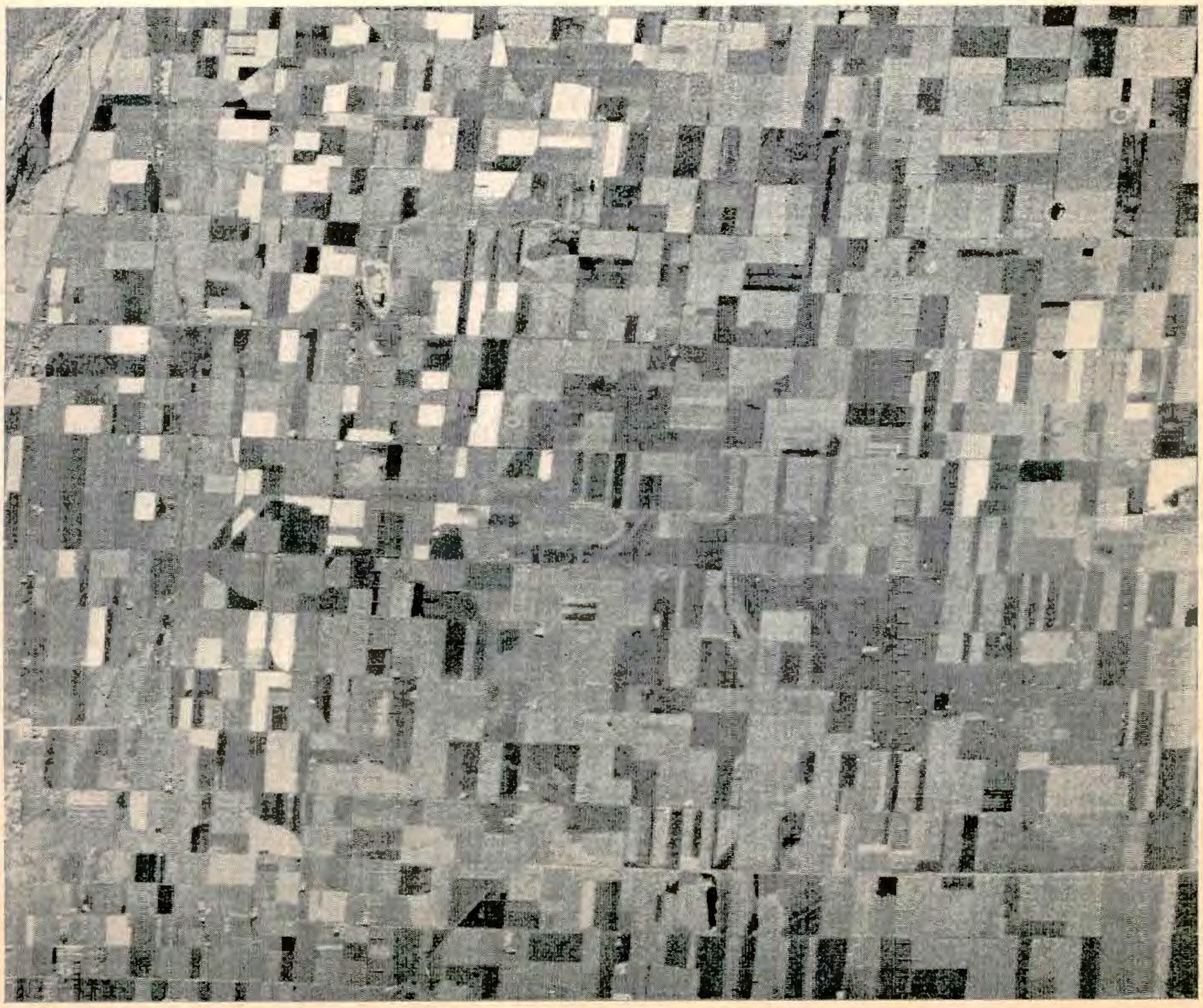
Additional Applications

The catalogue of uses for remote sensing is extensive. In forestry, for example, it is possible in small-scale photographs, such as those from spacecraft, to delineate the timberland, brushland and grassland in a wild area. With proper film and filter it is possible to differentiate the three major types of timber—hardwood, softwood and mixed wood. In larger-scale photographs one can determine the size of trees, the density of growth and the volume of timber. Foresters also use aerial photographs to detect trees that are diseased or infested with insects. Aerial photographs can be used to help in the planning of forest roads and of means for fighting forest fires.

The management of rangelands is assisted by remote sensing. From photographs one can learn the species of vegetation in an area, together with their volumes and their forage value. Photographs also reveal other data pertinent to range management, such as watering places, salt ground, plants that are poisonous to livestock, highly erodible sites and areas that need reseeding.

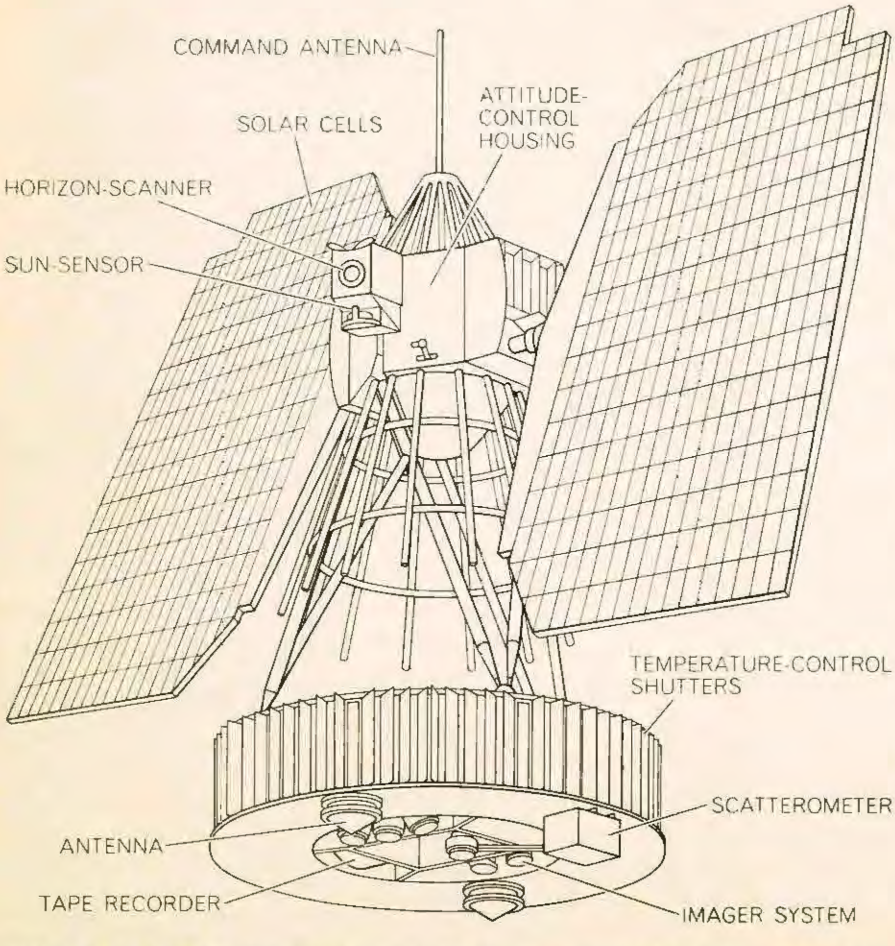
Wildlife managers can use aerial photographs for censuses of various kinds of animals and fish. The information is important in determining the impact of hunting, fishing and the works of man on fish and wildlife populations.

Administrators of agricultural programs need information on the type of crop growing in each field of a large area, the vigor of each crop and the probable yield. Where crops lack vigor, the agri-



RADAR IMAGE of farmland in Kansas shows certain types of crops more clearly than images from other bands of the spectrum could. Lightest fields, for example, contain sugar beets. Clear radar images can be obtained day and night and through clouds.

ADVANTAGE OF RADAR in penetrating a dense cover of vegetation to reveal the geologic structure of the terrain appears in a radar view of an area in the Sierra Nevada. The longer the wavelength at which radar operates, the better the radar penetrates vegetation.



UNMANNED SATELLITE that will sense data in several wave bands and transmit the information to earth by television may be in operation by 1970. The U.S. Department of the Interior and the National Aeronautics and Space Administration have been working on plans for such a spacecraft, to be known as EROS for Earth Resources Observation Satellite.

culturist wants to know what is wrong. All such information can often be obtained through the interpretation of aerial photographs if the photographs have been made under appropriate conditions, including the scale, the type of filter and film and the seasonal state of development of the crops.

Work already done along these lines has indicated that the classification of crops and land use in six categories will suffice for the preliminary assessment of almost any agricultural area. The categories are orchard crops, vine and bush crops, row crops, continuous cover (such as alfalfa and cereal crops), irrigated pasture crops and fallow ground. Each of these categories can be recognized by an experienced interpreter of photographs; usually he can also make further identifications of specific crop types within each of the six categories.

Let us consider the matter of crop vigor a little further. The first photographic evidence of loss of vigor due to black stem rust in wheat and oats or to blight on potatoes is to be found in the near infrared part of the spectrum, where reflectance rather than emission phenomena are of primary importance. On positive prints made from infrared photography the unhealthy plants register in abnormally dark tones. The technique is successful even in photographs made from spacecraft. Moreover, haze does not interfere appreciably with the technique because haze is easily penetrated by the long wavelengths used in making infrared photographs.

Water resources are susceptible to a degree of management through remote sensing. Aerial photography can show the area and depth of snowpacks on important watersheds at various times of the year. By following seasonal changes in the snowpack hydrologists can more intelligently regulate the impounding and release of water in reservoirs. Watershed managers also need to keep track of vegetation in order to estimate the loss of water to plants.

Vast ocean areas, about which a great deal remains to be learned, can be surveyed by remote sensing, particularly from spacecraft. Typically a camera in a satellite orbiting the earth can photograph a strip 3,000 miles long in 10 minutes, so that it is easily possible to keep track of changes over huge reaches of ocean. Among the phenomena that can be followed are the flow of currents, the course of tidal waves and the movements of marine animals, kelp beds and icebergs.

Many other applications of remote

sensing come to mind; I can only touch on them. Numerous archaeological sites have been discovered through conventional aerial photographs; it is probable that spacecraft photographs will reveal still more sites. Tax authorities can use aerial photographs to update maps showing land use and to spot efforts to change a land use without detection, such as by turning timberland into farmland while leaving a strip of forest along the road that a ground-based tax assessor might be expected to travel. Violations of law often show up in photographs; examples are illegal mining or logging in remote areas, pollution of waters by illegal dumping of chemicals, release through industrial smokestacks of materials that contribute to smog, and fishing in waters where fishing is prohibited. The analysis of such disasters as floods, fires and hurricanes can be assisted by the study of remote-sensing data, and the information so obtained can be used in making emergency decisions and in combating future catastrophes of a similar nature.

Techniques of remote sensing are in a fairly early stage of development. Many of the applications I have suggested are therefore yet to be realized in practice. Their success, and the achievement of still other applications, will depend heavily on further research into the kinds of data that can be obtained from remote sensing—in learning, for example, where in the spectrum a certain plant disease will appear most distinctly. My colleagues and I have found it helpful to set up arrays of various natural resources and photograph them from high but stationary places, such as water towers and the tops of cliffs. The work helps to determine, economically and under controllable conditions, the bands of the spectrum that might best be used in remote sensing directed at finding the same resources.

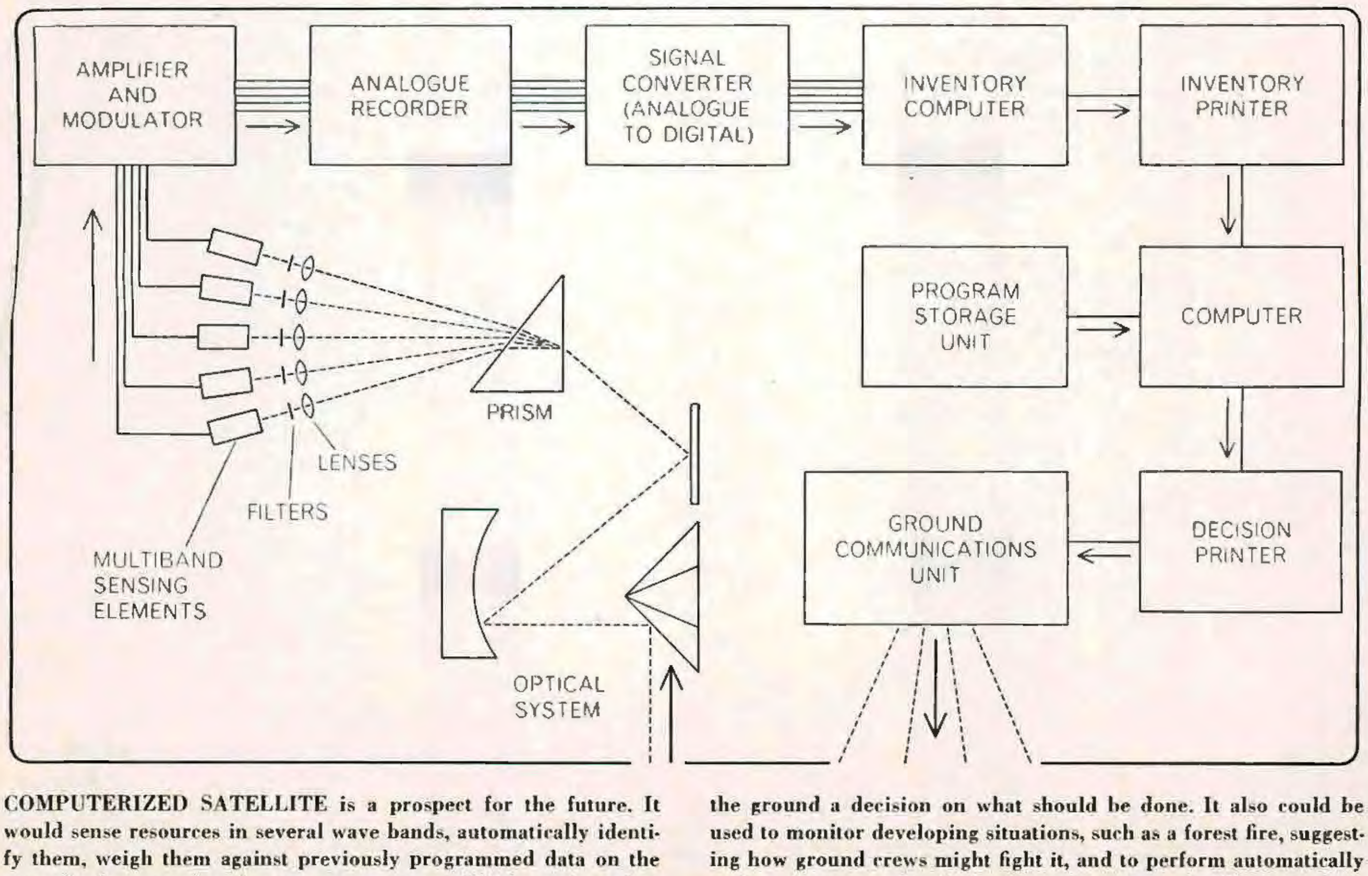
A Prospect

I can foresee the possibility that the techniques for remote sensing will evolve into a highly automatic operation, in which an unmanned satellite orbiting the earth will carry multiband sensing equipment together with a computer. Thus equipped the satellite could, for any particular area, take inventory of the resources and produce a printout that would amount to a resource map of the area. The computer could then use the inventory data in conjunction with preprogrammed factors (such as what ratio of costs to benefits would be likely to result from various resource management practices) and could reach a decision for the optimum management of the resources in the area. The decision would be telemetered to the ground for whatever action seemed necessary.

As a simple example, the satellite's sensors might spot a fire in a large forest. Its computer might then derive information on the location and extent of the fire and could assess such factors as the type and value of the timber, the direction and speed of the wind and the means of access to the fire. On the basis of the assessment the computer would send to the ground a recommendation for combating the fire.

Capabilities of this kind need not be limited to emergencies. Many routine housekeeping chores now done manually by the resource manager could be made automatic by electronic command signals. Examples might include turning on an irrigation valve when remote sensing shows that a field is becoming too dry and turning off the valve when, a few orbits later, the satellite ascertains that the field has been sufficiently watered.

A satellite of such capabilities may seem now to be a rather distant prospect. After a few more years of developing the techniques for remote sensing the prospect may well have become a reality.

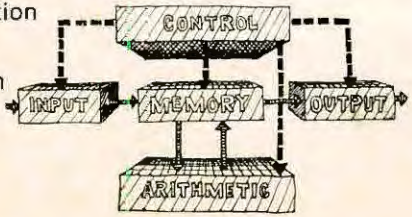


COMPUTERIZED SATELLITE is a prospect for the future. It would sense resources in several wave bands, automatically identify them, weigh them against previously programmed data on the cost effectiveness of various management possibilities and send to the ground a decision on what should be done. It also could be used to monitor developing situations, such as a forest fire, suggesting how ground crews might fight it, and to perform automatically such tasks as turning irrigation valves on and off as required.

While the rest of the semiconductor industry tried to squeeze enough ICs on a chip to get into the MSI/LSI business, Fairchild turned systems inside out. We were looking for an intelligent alternative to component mentality. Our investigation led to a whole new set of design criteria for medium and large scale integration devices.

A computer isn't a computer.

It's a digital logic system. It has the same functional needs as any other digital system: control, memory, input/output and arithmetic. There's no logical reason to custom design a complex circuit for each system. That's why Fairchild MSIs and LSIs are designed to function as fundamental building blocks in *any* digital logic system. Even if it's a computer.



A little complexity goes a long way.

Anybody can package a potpourri of circuitry and call it MSI or LSI. But, that's not the problem. Why multiply components, when you should divide the system? Like we did. We found that sub-systems have a common tendency toward functional overlap. There are too many devices performing similar functions. More stumbling blocks than building blocks. Our remedy is a family of MSIs and LSIs with multiple applications. The Fairchild 9300 universal register, for example, can also function as a modulo counter, shift register, binary to BCD shift converter, up/down counter, serial to parallel (and parallel to serial) converter, and a half-dozen other devices.

Watch out for that first step.

There are all kinds of complex circuits. Some of them have a lot of headache potential. Especially if you want to interface them with next year's MSIs and LSIs. We decided to eliminate the problem before it got into your system. All Fairchild building blocks share the same compatible design characteristics.