*Capabilities and Limitations of Remote Sensors**

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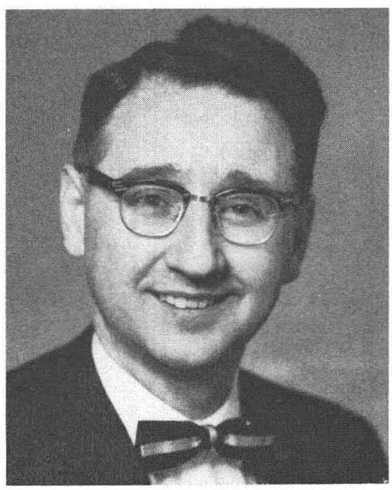
ABSTRACT: *Modern remote sensor imagery has greatly improved in recent years. Until recently, airborne imagery, whether for mapping or intelligence purposes, was collected on sunny, cloud-free days within predetermined time periods. Now passive and active remote sensors can collect data twenty-four hours a day in the visible, infrared and microwave regions of the electromagnetic spectrum.*

No individual sensor has reached such a state of development that its store of information cannot be increased by supplemental use of other systems. Radar, for example, collects its data through clouds or at night. Infrared systems detect thermal variations between adjacent features. Neither system, however, approaches modern cameras in resolution, dynamic range and detail.

SINCE World War II the term "remote reconnaissance" has involved more than better cameras, sharper lenses or faster films. No longer are image analysts restricted to aerial photography alone. Instead, their analyses span the electromagnetic spectrum by means of infrared, radar and other even more sophisticated systems. They extract data from sections of the electromagnetic spectrum several million times wider than that available to conventional camera systems.

Of what value is this additional coverage? Can it really provide information not obtainable with good aerial cameras? How do images generated by infrared and side-looking radar systems compare with conventional photography? Will they, as some claim, make aerial photography obsolete?

The added coverage has revealed new identification signatures for both natural and cultural features in spectral areas beyond cameras' capabilities. Under certain conditions, infrared and radar systems can produce imagery of specific subjects of nearly photographic quality. But they will only supplement, not replace, aerial cameras—at least not for a few years. A comprehensive system still needs several sensors to satisfy the needs of military reconnaissance or commercial exploration.



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To realize the capabilities and limitations of these sensors one must first understand the electromagnetic spectrum.

All electromagnetic energy is generated as waves whose lengths change from microscopically small at one end of the spectrum to fantastically long at the other. Figure 1 shows a segment of the electromagnetic spectrum. The visible spectrum—until recently the only part available to the interpreter—

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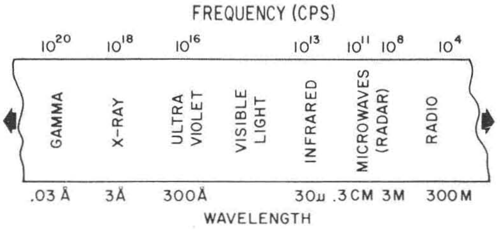

FIG. 1. Segment of electromagnetic spectrum.

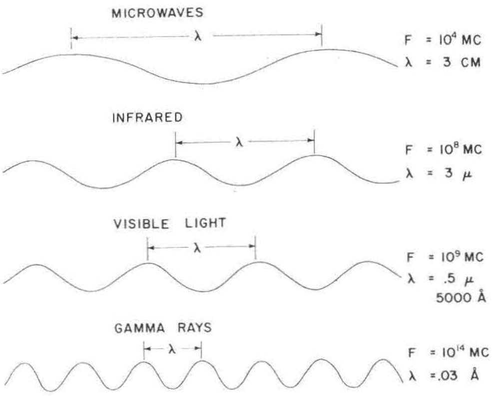

FIG. 2. Relation of wavelength to frequency.

uses only a minute part of the available energy (wavelengths from about 4,000 to 7,600 Angstroms or .4–.76 microns).

Other parts of the spectrum transmit energy at different wavelengths:

Infrared radiations—less than 3 to about 1,000 microns
Microwaves (including radar)—less than a centimeter to about 3 meters
Gamma rays—about .03 Angstroms

No sharp cutoff exists between bands. Rather, a smooth transition occurs, like gradual changes in a rainbow. There, for example, one cannot select the exact point where blue becomes green.

Frequency (the number of waves passing a given point per second) varies inversely with wavelength because all electromagnetic energy travels at the speed of light. Figure 2 shows relationships between wavelength and frequency for microwaves, infrared radiations, visible light and gamma rays. This figure merely shows representative comparisons. It is not to scale.

Each sensor reacts only to energy bands of specific frequency and wavelength; radar receivers cannot detect visible light; transmitted microwaves are invisible to infrared scanners.

Figure 3 shows how airborne remote sensors are either passive or active. Passive systems (some infrared devices, cameras) detect radiations that would be present whether or not the sensor were operating.

Active sensors, like radar, record echoes of reflected electromagnetic energy which they themselves transmit.

Aerial cameras produce their best imagery on cloudless, hazefree days, but with new techniques and equipment they do obtain reasonably good imagery on clear nights. Figure 4 shows that radar and infrared systems can overcome these limitations.

Infrared systems also produce good daytime imagery. However, since they respond to energy radiated from beyond the visible spectrum, night infrared missions with middle and far infrared sensitivity yield excellent results. For many purposes, far infrared data flights obtain their best imagery after dark when there is no interference from solar insolation. Military needs for nighttime operations are obvious.

Infrared radiation may penetrate dust and haze, depending on the size of the aerosol particles, but clouds, high surface winds and rain greatly reduce image quality.

Radar, an active sensor, provides its own source of energy. Therefore, it too is independent of time-of-day. Its longer wavelengths

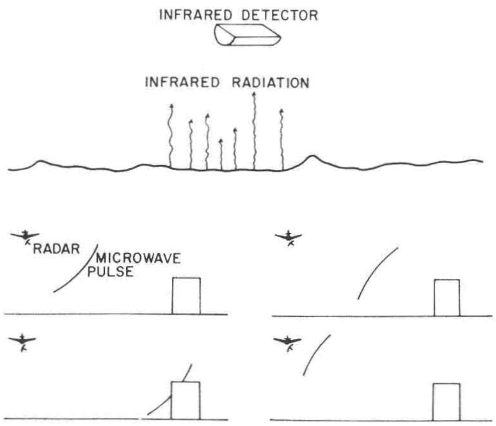

FIG. 3. Difference between passive and active sensors.

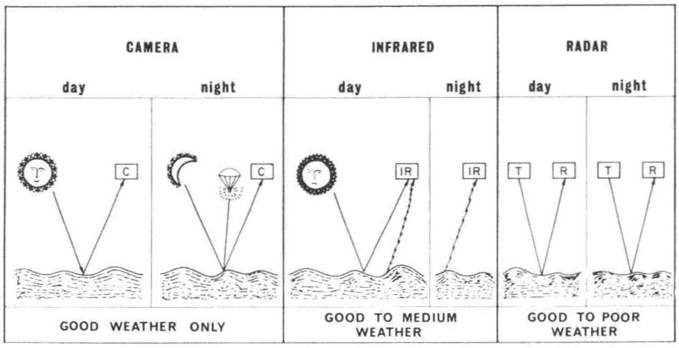

FIG. 4. Time-weather capabilities of remote sensors.

penetrate fog, haze and clouds with minimum signal loss. Rains attenuate the signal, but the extent depends on system wavelength and rainfall rate. Thick, moisture-laden clouds, however, can effectively block transmitted waves. To what extent these factors affect radar imagery depends on several system parameters.

All three systems can be "tuned" to be more selective to specific frequencies within their operational bands. Narrow band film-filter combinations enable cameras to record spectral responses of one color. Filters are often added to infrared systems to eliminate effect of solar reflection below the middle or far infrared range, depending on the system.

Figure 5 shows infrared energy transmission through a standard atmosphere and spectral sensitivity of a mercury-doped germanium detector. The atmosphere's composition allows relatively undisturbed transmission of infrared radiations in the 2–5 and 7–15 micron ranges. However, the detector, a standard in the industry, transmits from the edge of the visible spectrum to about 15 microns without the interruption between 5 and 7 microns. During daylight hours, therefore, it records some solar effects.

Despite excellence of nighttime infrared imagery, some mineral surveys are best conducted during the day because of the rate of absorption and transmission of infrared radiation. However, the infrared system must include filters sensitive to infrared radiations only, to effectively eliminate reflections from the rest of the spectrum.

Pulse repetition rate, polarization, power, radar system resolution and sensitivity are functions of wavelength and gain setting. For example, weather radars (which require only moderate resolution) use long wavelength systems; terrain reconnaissance and mapping radars use much shorter wavelengths (comparatively) to record natural and cultural features with almost photographic clarity.

System components (such as Cathode Ray Tube and film) cannot record with equal discrimination all signal levels received at the antenna. Whether the film records maximum differences between high or low intensity signals depends on the settings according to mission's main purpose. In Figure 6, if most of the available film density range is used to

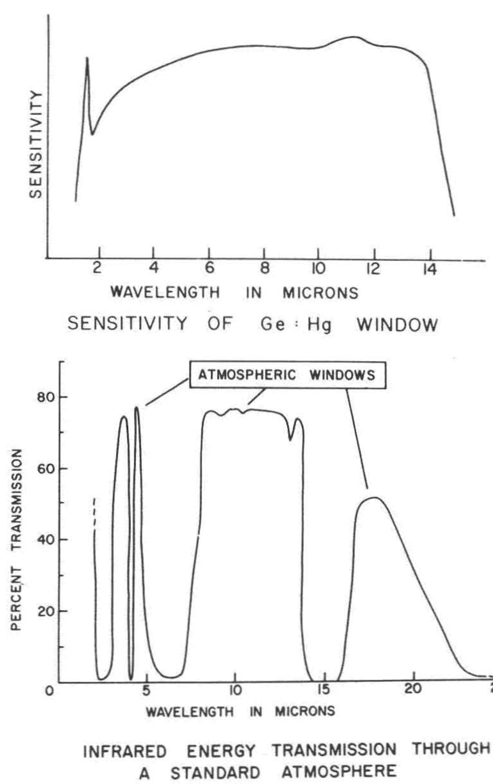

FIG. 5. Spectral detectivity of mercury doped germanium infrared detector compared to infrared energy transmission.

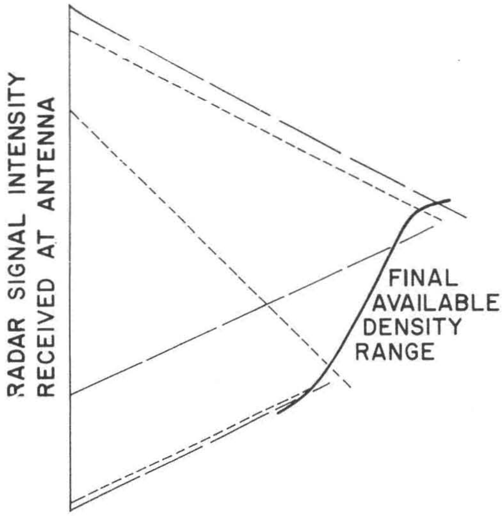

FIG. 6. Effects of gain setting on negative density.

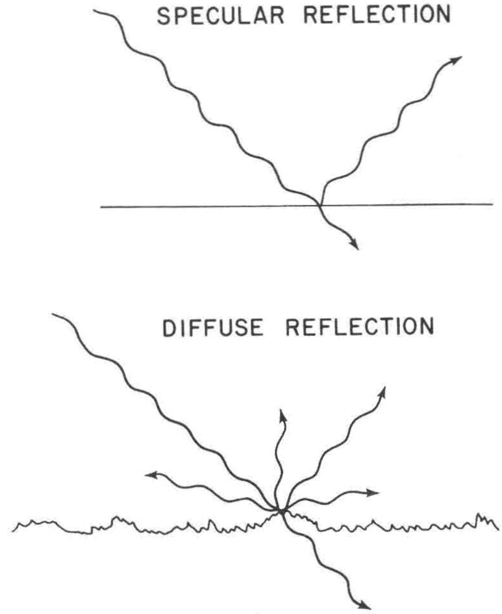

FIG. 7. Specular vs. diffuse reflections.

record differences between low level signals, strong intensity returns are compressed into a small density range. Much of the signal is, in reality, "clipped" and recorded at one density level. Conversely, setting the gain to discriminate between strong signals loses low level separation. Farmland, orchards and open country are typical low-level returns. Urban and industrial areas give strong returns.

An object's surface smoothness and orientation affects its radar image. Surfaces smoother, i.e., with irregularities smaller than the wavelength of the impinging electromagnetic energy, will reflect most energy specularly, or mirror-like, while rough surfcaes create mainly diffuse reflections. The smooth surface of Figure 7(a) acts like a mirror: the angle of reflection equals the angle of incidence. In this case, impinging energy is reflected away from the transmitter-receiver. The multifaceted rough surfaces of Figure 7(b) scatter energy unequally (diffusely) in all directions. Some energy eventually returns to and is recorded by the receiver.

Because visible spectrum wavelengths are so short, most surfaces reflect light diffusely regardless of orientation. Longer microwaves create more specular reflections off the same surfaces. For example, aim a flashlight at a wall, first perpendicularly, then at an angle. One sees the wall equally as well regardless of the illuminating angle. A radar system illuminating a similar wall shows much stronger returns for head-on orientations than oblique.

On aerial photographs, images of bodies of water frequently vary in tone. Wide density ranges often occur on the same negative. Many times, these density changes vary with respect to water depth; other times to the sun angle.

With radar, water's smooth surface reflects most transmitted microwave energy specularly; it gives a "no return" image.

Radar can record some of water's phenomena, however. Surfaces broken by breakers, waves, or submerged rocks are often detectable. Contrast between normal no-return images and slight returns off broken water usually are sufficient to assure surface detection of submerged features.

Infrared systems can extract considerable information from bodies of water. Hot effluents discharged into streams or lakes are readily detectable because of temperature differences between them. Densitometric analyses show how far and in what direction

	CAMERA	INFRARED	RADAR
DAY/NIGHT	5	10	10
HAZE-FOG PENETRATION	3	6	10
CLOUD PENETRATION	1	2	9
TEMPERATURE DISCRIMINATION	2	10	1
SUB-SURFACE DETECTION	4	6	3
STEREO CAPABILITY	10	2	3
ACCURATE IMAGE REPRESENTATION	9	6	5
LONG-RANGE CAPABILITY	7	4	8
RESOLUTION	9	7	5
INTERPRETABILITY OF IMAGERY	9	6	6
AVAILABILITY OF EQUIPMENT	10	4	4

POOR = 0 GOOD = 10

FIG. 8. Remote sensor comparison.

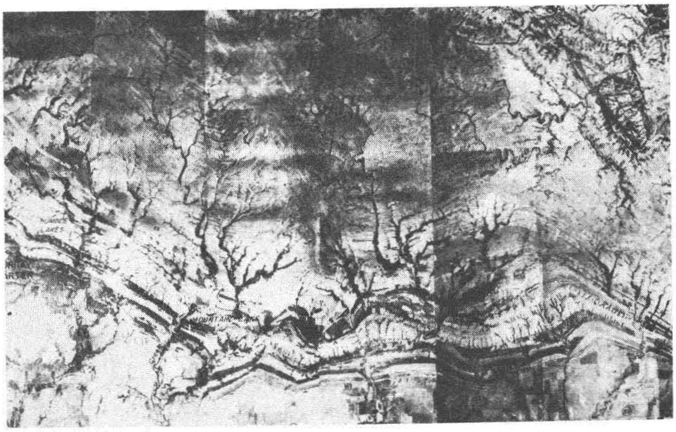

FIG. 9. Photo index, Arbuckle Mountains, Oklahoma.

effluents travel before the stream or lake absorbs them. Chemical wastes or other polluted discharges should be as readily detectable because of the temperature anomalies they create.

Figure 8 summarizes the advantages and disadvantages of remote sensors. No single sensor possesses all requirements for an optimum device. But neither does any sensor have so many disadvantages that it is valueless. Cameras possess the best resolution and give geometrically accurate reproductions; infrared systems record minute temperature differences; side-looking airborne radars operate independently of the clock in almost all weather and maintain constant image quality (up to 3rd order planimetric accuracy) over extremely long ranges.

But some remote sensor problems require the interpreter to be very cautious. One of infrared's most confusing situations occurs when an object's temperature is the same as its background. Then the two cannot be separated. Properly positioned metal corner reflectors produce radar reflections as strong as large industrial complexes. However, to hide a large object—like a factory—from radar detection presents more serious problems.

Optimum systems then, consist of more than one sensor, each contributing its special information. For example, Figure 9 is a photo index mosaic of the Arbuckle Mountains, Oklahoma. Detail is sharp, but at this scale it shows only relatively gross objects. (Of course, stereo analysis of the contact prints will reveal much data.) Figure 10 shows unclassified duplicate radar images of the Arbuckles collected by what is now a primitive radar system. Many features of geologic interest (annotated on the lower photo) are readily apparent. Most important, the radar image could have been taken day or night in virtually any weather that allowed the aircraft to fly. The data collection phase of this geologic mapping program took less than 6 hours.

Figure 11 is an unclassified high altitude

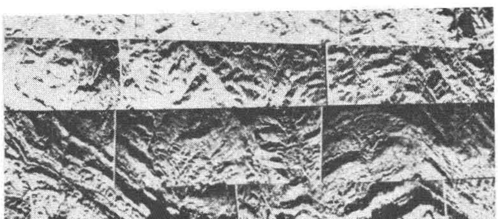

FIG. 10. Radar mosaics, Arbuckle Mountains, annotated and unannotated.

FIG. 11. Infrared image of Dallas, Texas.

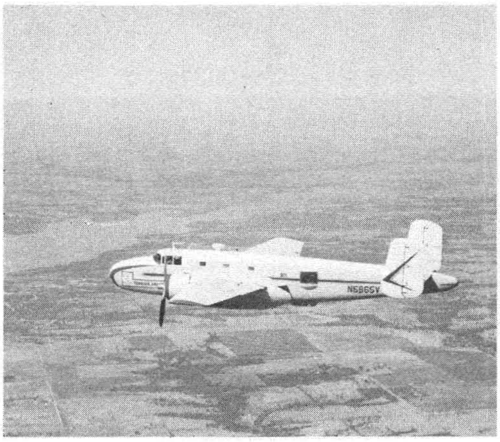

FIG. 12. Multi-sensor equipped B-25 aircraft.

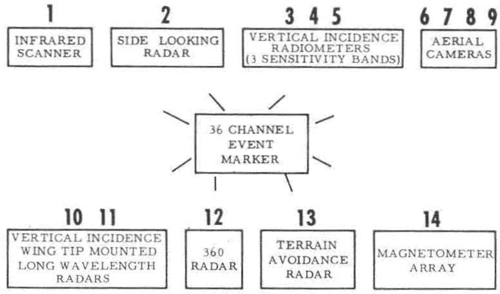

FIG. 13. Texas Instruments' multi-sensor system concept.

nighttime infrared image of Dallas, Texas. One can see a complete road pattern, stream, open areas, parks and many individual buildings across the entire format.

Many of the streams and roads are below tree canopies that would preclude their detection in the visual spectrum.

To exploit the advantages of multisensor reconnaissance, Texas Instruments converted a B-25 twin-engine aircraft into a multisensor platform. (Figure 12) We have equipped it with a side-looking radar, a far-infrared scanner, two aerial cameras and two hypersensitive radiometers. With this aircraft we have acquired, under government and commercial contracts, multisensor imagery and performed interpretations of various cultural and natural features in ten states. Current planning calls for outfitting a much larger aircraft with an even more sophisticated, integrated multisensor system. Figure 13 is a block diagram of this system. It will have four radar systems (side-looking, 360° scan, vertical incidence and terrain avoidance) a far-infrared detector, several aerial cameras, three radiometers and a magnetometer array. The vertical incidence radar system is based upon Texas Instruments terrain analysis research performed for the Army Engineers at Vicksburg. With these sensors we will be able to study many decades of the electromagnetic spectrum and broaden its application to remote reconnaissance or exploration problems.