*Terrain Mapping by Use of Infrared Radiation**

DAVID E. HARRIS and CASPAR L. WOODBRIDGE,
HRB-Singer, Inc.,
State College, Pa.

ABSTRACT: *In the last decade much progress has been made in the development of techniques for obtaining thermal maps of terrain using airborne scanning devices. To date the spectral region from visible light to about 14 microns has been exploited.*

Present state-of-the-art restricts the system designer to the use of single element infrared detectors or to very simple arrays of a few elements.

This paper describes a line-scanning technique that has been successfully applied in obtaining thermal terrain maps from the air. Pertinent design parameters are discussed and various factors that limit performance are analyzed. Thermal maps of various types of terrain illustrate the usefulness of the mapping technique.

I. INTRODUCTION

INFRARED radiation is generated by vibration and rotation of the atoms and molecules within any material whose temperature is higher than absolute zero. Consequently, practically everything in man's surroundings, and man himself, radiates energy in the infrared portion of the electromagnetic spectrum. The generally accepted IR spectrum lies between the wavelengths of 0.72 and 1,000 microns.

Since its spectrum falls between those of visible light and radio waves, infrared radiation exhibits some of the characteristics of both visible light and microwave radio waves. It can be optically focused and directed by lenses and mirrors, or dispersed by prisms. It can also propagate through some materials that are opaque to visible light.

While the existence of infrared energy has been known since the latter part of the 17th century, relatively little use had been made of it until the 1920's when IR spectroscopic techniques were first applied to the chemical industry. By 1935, the value of IR spectroscopy as an analytical tool was fully realized.

Perhaps the major factor influencing the relatively slow development of infrared techniques was the lack of sensitive detectors. Intensive research in Germany just prior to and during World War II resulted in the development of new, highly sensitive detectors. And with the emergence of solid-state physics as a major science since 1945, great strides have been made both in sensitivity and in response to longer wavelengths.

Although infrared-sensitive mosaic devices are under development, they are still in the laboratories, and a mapping system for practical use at present must utilize a single-element detector in conjunction with some type of optical scanner.

II. A LINE-SCANNING TECHNIQUE

Many scanning patterns have been investigated but perhaps the simplest to generate and implement is the line-scanning pattern shown in Fig. 1. Here the scanning of the area of interest makes use of the forward motion of the aircraft. A scanning device in the aircraft permits sampling incremental areas of the scene along a straight line normal to the flight path. At any instant the field of view is represented by a cone having a small

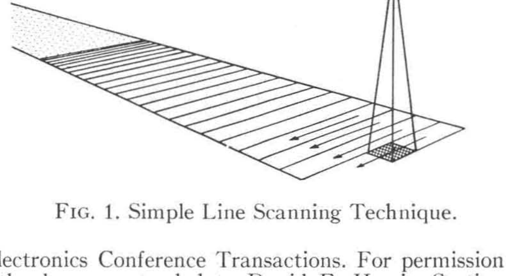

FIG. 1. Simple Line Scanning Technique.

* This paper was prepared for the National Electronics Conference Transactions. For permission to republish in PHOTOGRAMMETRIC ENGINEERING, thanks are extended to David E. Harris, Section Manager of HRB-Singer, Inc.

included angle, α. A basic requirement of the technique is that the line-scan rate be high enough to provide at least contiguity of the scanned strips of the scene.

The width of the scanned strip in the direction of flight is directly proportional to the altitude of the aircraft above the terrain and to the instantaneous angular field of view, α. So to insure complete area coverage, the minimum line-scan rate is inversely proportional to altitude and to the angular field of view, α. It is directly proportional to ground speed. Assuming a linear repetitive scanning pattern, as shown in Fig. 1, the minimum line-scan rate becomes

$$\eta = \frac{v}{h\alpha} \qquad (1)$$

where:

η = line-scan rate—lines-per-second
v = ground speed—ft./sec.
h = aircraft altitude—ft.
α = instantaneous field of view—radians

This relationship is plotted for several values of α in Fig. 2.

The signal bandwidth generated by the scanning pattern shown in Fig. 1 may be simply derived. The number of incremental picture elements sampled per second may be expressed as follows:

$$N = \frac{\beta\eta}{\alpha D} \qquad (2)$$

where:

N = data acquisition rate—elements/second
β = total angular field of view—radians
η = line-scan rate—lines/second
α = instantaneous field of view—radians
D = line scan duty cycle

The signal bandwidth is not a primary consideration here, but the reciprocal of N, the dwell time per element, may be.

If the value of $1/N$ approaches, or is less than, the response time constant of the available detector, it may be impossible to meet the scan speed requirements. Equalization techniques in the video amplifier will permit extending the scan rate to a limited degree, but at the expense of over-all system sensitivity.

Actually the signal of interest is represented by the changes in amplitude at the detector output in scanning from one picture element to the next. In other words, the significant data in deriving a thermal map are the variations in effective temperature across the scene, not the absolute temperature values. We are interested, then, in the incremental thermal sensitivity of the system.

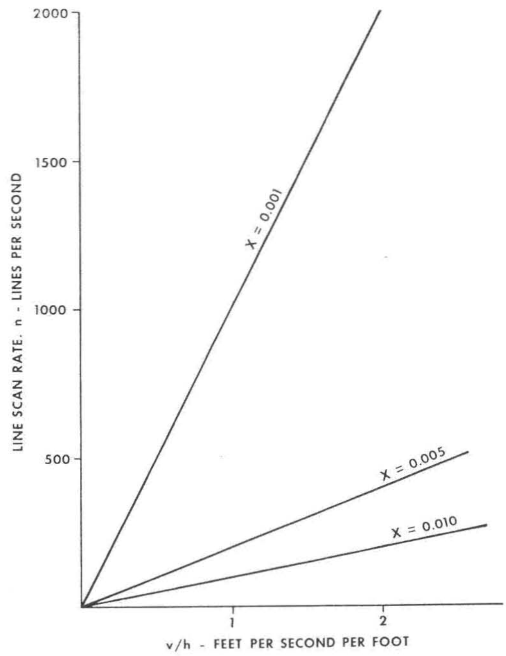

FIG. 2. Scan Rate Curves.

The radiation emitted by a body at a given temperature is proportional to the characteristics of its surface. This leads to the concept of "emissivity" and the "black body." A "black body" is by definition any object which completely absorbs all radiation incident upon it. Conversely, the radiation emitted by a black body at any given temperature is the maximum possible. Its emissivity is said to be unity.

A highly polished surface is an extremely poor radiator and absorber; its emissivity is close to zero.

Most surfaces of interest in thermal mapping lie between these two extremes in emissivity. Since determination of emissivities of portions of a scene is practically impossible, it is convenient to adopt the assumption that the entire scene radiates as a black body, and to interpret the flux emanating from the scene as representing "equivalent radiation temperatures."

The radiation emitted from a black body is given by Planck's Law:

$$W_\lambda = C_1\lambda^{-5}\left(\epsilon \frac{C_2}{T} - 1\right)^{-1} \qquad (3)$$

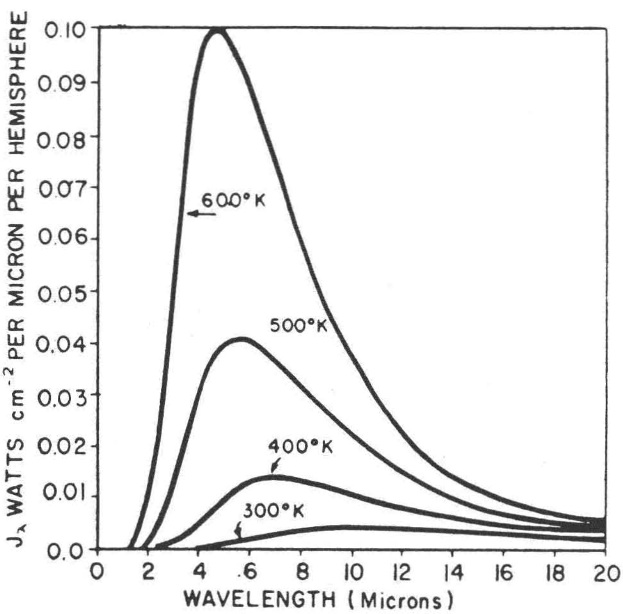

FIG. 3. Spectral Distribution of Energy for Perfect Emitters.

where:

W_λ = radiation at a given wavelength emitted per unit surface area per unit wavelength interval into a hemisphere.

λ = wavelength

T = absolute temperature

C_1 & C_2 = constants

Fig. 3 is a plot of equation (3). Both total radiation and spectral distribution are functions of the temperature of the black body.

Infrared detectors of different types exhibit different spectral response characteristics. A few typical detector response curves are shown in Fig. 4. To achieve maximum thermal sensitivity it is desirable to select a detector whose spectral response encompasses as much as possible of the spectral radiation distribution from the object of interest.

Transmission characteristics of the atmosphere must be considered since it attenuates the energy radiated from the scene. The major cause of attentuation is water vapor and this is proportional to the amount of precipitable water in the path. Fig. 5 illustrates the transmission characteristics of the atmosphere.

In a typical design problem, one might wish to determine the thermal sensitivity that could be expected for a specified set of conditions including:

1. Detector characteristics
2. Average effective temperature of the scene
3. Instantaneous Field of View
4. Optical aperture
5. Atmospheric path

The solution involves computation of the total incident power on the detector element, the determination of the change in incident power discernible from the detector noise, and the relation of this power increment to an

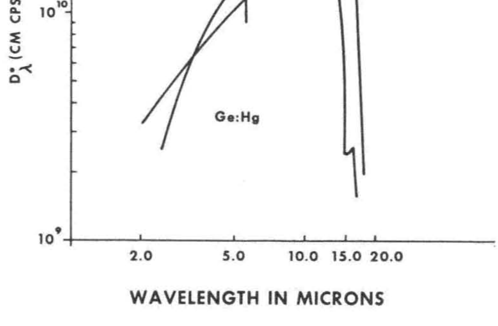

FIG. 4. IR Detector Spectral Response.

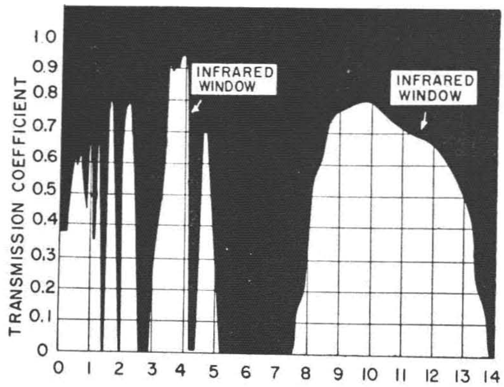

FIG. 5. Transmission Spectra of the Atmosphere.

effective temperature increment. This computation is quite involved, and requires an integration of the product of radiated power, atmospheric transmission, and detector response over the appropriate portion of the spectrum. The computation is easily performed by an electronic computer.

III. A Line-Scanning System

The basic elements of the airborne thermal mapping system are shown in Fig. 6. The line-scanning function is performed by means of a plane mirror scanner whose axis of rotation is parallel to the longitudinal axis of the aircraft. The mirror reflects radiation to a parabolic mirror that is used to focus the radiation on the IR detector. This optical system focuses a bundle of radiant flux on the detector; we are not concerned here with forming and detecting an image of the type that is obtained for conventional photography.

The IR detector senses the incoming radiation, and converts changes in the radiation into an electrical signal. This signal is amplified by solid-state circuitry and is used to modulate the current through a crater lamp

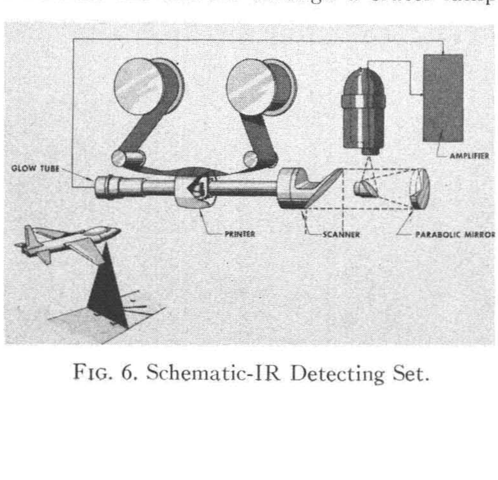

FIG. 6. Schematic-IR Detecting Set.

whose output is an intensity modulated spot of light. An image of the crater is focused on the surface of a photographic film and is scanned across the film in synchronism with the rotating scanner. The film moves across the exposure station at a speed proportional to the aircraft speed-to-altitude (v/h) ratio, and the result, after processing, is a strip thermal map of the area flown over, in which film density represents relative effective radiation temperature.

IV. Thermal Maps

Some examples of the thermal mapping capability of the technique and system just described are shown in Figs. 7, 8, 9, and 10. When viewing these results, there is a natural tendency to compare them with aerial photography. It is important to remember, however, that the similarity between the thermal map and the conventional photograph ends with the pictorial characteristics of the image. The distribution of contrast in each image represents entirely different information. In the photograph the distribution is determined by variations in reflectivity of the elements of the image, while the thermal map represents the pattern of energy radiated from the scene due to its temperature and emissivity distribution.

In Fig. 7 is shown a thermal map of a section of Manhattan made about 11 p.m. in the Winter of 1957-58 using a detector sensitive in the 0.3 to 5 micron spectral region. In the Central Park area the large lake was not frozen while the smaller bodies of water were ice-covered. The paths appear warmer than the background probably because of the higher emissivity of the surface material. It is interesting to note the hot spots in the surrounding city.

Fig. 8 is a comparison of the use of the visible and the 0.3 to 2.5 micron spectral region. Both strips were made using the same line-scanning device during the afternoon of a summer day in 1953. The strip on the top was made using an infrared detector while the one on the bottom is the result of using a detector in the visible spectrum. The visible light strip is the result of reflected sunlight while the infrared strip represents both radiation from the scene and reflected solar energy.

The outstanding feature is the different appearance in the two images of the small stream and the road. In the infrared image the creek appears at a high contrast while in the visible image it almost disappears into the background.

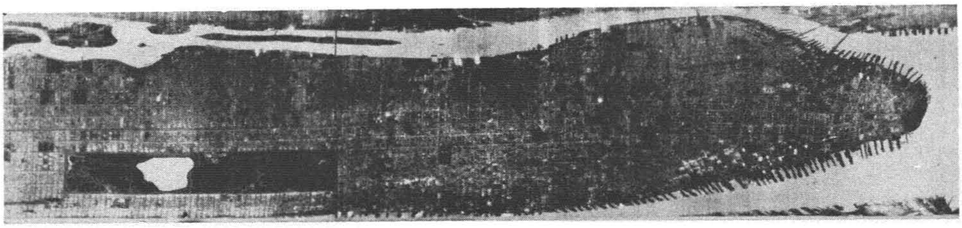

FIG. 7. IR Thermal Map of Manhattan Island.

The cultural targets show more clearly in the visible spectrum perhaps due to a greater range of reflectivities. The vegetation appears quite similar in the two.

An infrared image of a section of the New Jersey coast is shown above a map section of the same area in Fig. 9. Of interest here is the surface temperature effect in the water area induced by the conformation of the bottom. It gives the impression of being able to see through the water to the bottom.

The river at the top of the picture shows a definite outflow of warmer water into the inshore area. This effect has been used in the study of local current distributions and sewage outfalls in inland waterways.

Fig. 10, made at midnight in the summer of 1959, is a good example of the different emission of plowed and unplowed fields, the one being loose and the other compacted and covered with grass.

The highway in this image is warmer than the background in contrast to the cooler appearance noticeable in daytime infrared images.

V. CONCLUSIONS

In general, differences in surface condition and temperature can be detected in an infrared thermal map. This is a different type of information than that collected with photography or radar.

In the application of any photo-type

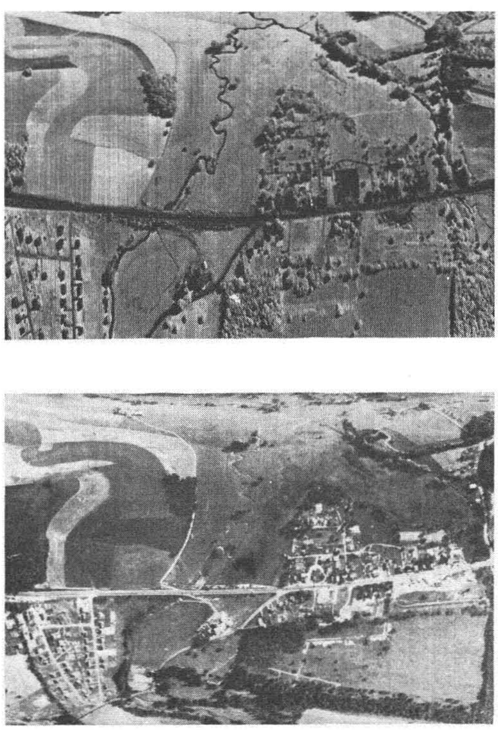

FIG. 8. IR Thermal Map (Top) and Visible Light (Bottom) Results—Same Area.

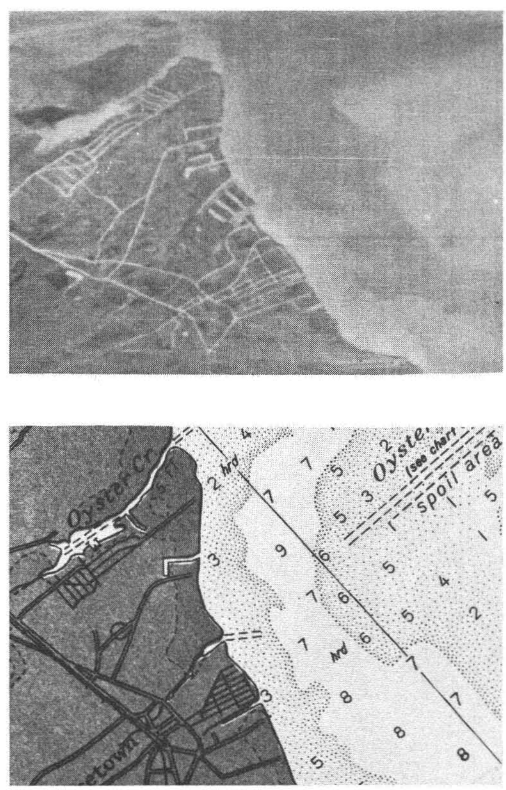

FIG. 9. IR Thermal Map (Top) of New Jersey Coast. USC&GS Chart (Bottom).

imagery the primary information is derived from the tonal structure of the image. In photography and radar the image represents a distribution of reflecting surfaces in the face of some form of illumination. Photography involves the reflection of visible light over a narrow spectral region, while radar involves the reflection of energy in a narrower spectral range. In either case the illumination provides the source of energy and defines to a great extent the character of the reflected energy.

For infrared imagery the energy source lies in the temperature characteristics of the scene itself; the emitted energy is a function not only of the physical characteristics of the surface but of the surface temperatures as well. One can envision many situations where temperature alone may be the significant defining factor. Incipient forest fires would probably be unmistakable, as would gas or steam fissures, hot springs and the like. A more subtle pattern would be formed by ocean currents and arctic polynyas and leads. In all of these cases the temperature differential alone would be sufficient to separate the source from its background.

Of equal significance, however, is the radiation differential produced by nothing more than a difference in the emission capability of the surfaces involved. In Fig. 10 the differences between plowed fields and turf was illustrated. For the same reason old snow has a different appearance than new snow, and wet or compacted earth from normal dry earth.

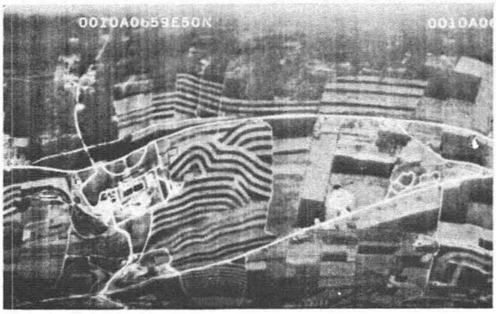

FIG. 10. IR Thermal Map of Nittany Valley.

This is where thermal mapping stands today. Terrain surface features in general can be defined by infrared imagery, and a great deal can be inferred from thermal maps by an interpretation that takes due account of the physical principles involved. Improvement in spatial and thermal resolution is being made, and results achieved to date indicate that thermal mapping is a very promising technique for the determination of terrain features.

Semi-Automatic Equipment for Statistical Analysis of Airphoto Linears

CARLO MAFFI and ENRICO MARCHESINI,
GEOMAP S. A., 29 Rue du Rhone,
Geneva, Switzerland

(*Abstract is on the next page*)

INTRODUCTION

THE study of ground-recognized fractures and joints has been developed into a tool for use in the fields of oil exploration, mining and hydrothermal energy exploration. The efficiency of this new tool is largely dependent upon the possibility of properly processing an enormous amount of individual data. The early attempts to draw inferences from ground observed fracture patterns have resorted to conventional, hand-operated statistical techniques for the preparation of frequency tables, histograms, polargraphs, based upon azimuth, length, and eventually the dip of the observed fractures. The painstaking process of data collecting on the ground, added to the laborious process of hand-computing, has resulted in strongly