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*Multiband Spectral System for Reconnaissance**

A special nine lens camera (Figure 1) having different films and filters takes simultaneous photographs in several regions of the spectrum.

(*Abstract on page 134*)

INTRODUCTION

AN AIRBORNE spectral reconnaissance and data reduction system is being developed and tested for detecting, recording and displaying the surface manifestations of underground nuclear explosions and large magnitude earthquakes. This work is being conducted by the Itek Corporation for the VELA Program of the Advanced Research Projects Agency, Department of Defense, through the Air Force Cambridge Research Laboratories.

The basic concept of the system operation is that a subsurface disturbance (explosion or earthquakes of comparable seismic magnitude) will produce physical manifestations affecting vegetation, terrain surface features, and terrain sub-surface features. Unique and specific absorption, emission, scattering, or reflectance signatures can be established for all such objects and materials, using available sensors, film and filters. The event will produce changes in these signatures which can be detected by airborne spectral reconnaissance in selected narrow bandwidths of the visible and near-infrared.

The use of this system in civil aerial photography can provide much information to enhance the photointerpretation of vegetation, soil, and geologic conditions.

SPECTRAL ENERGY CONSIDERATIONS

The airborne reconnaissance system is concerned with the remote sensing of reflected energy in the visible and near-infrared portion of the electro-magnetic spectrum or from about 0.35 to 5.0 microns. The airborne system depends on the sun as a source of reflected energy, and near optimum illumination is required because of the sensitivity of the photographic and spectrometer equipment. Reduced illumination due to cloud cover or low sun angle reduces the reflected energy below an acceptable level.

The solar energy spectrum expected on the ground during a typical good weather flight is shown in Figure 2. The solar energy spectrum rises to a peak in the visible and falls off beyond the near infrared to almost nothing beyond four or five microns. The smooth curve represents the energy distribution except for the sharper absorption bands.

Over half of the solar energy lies in the extended photographic region up to 0.9 microns. Most of the remainder is within the sensitivity of the lead sulphide detectors.

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FIG. 1. The Nine-lens Multiband Camera.

System Description

The spectral reconnaissance system consists of airborne sensors and data handling equipment. In addition, ground data collection equipment has been developed to aid in the collection of reliable ground data essential to the evaluation of the data collected by the airborne system.

The Airborne System

The airborne system consists of (1) a nine lens multiband camera, (2) two 70-millimeter frame cameras, (3) a skylight recording camera, (4) a cartographic camera (Type KC-1), (5) a spectrometer system, and (6) control console. The airborne equipment is designed to be in a RC-130 aircraft. The airborne sensors are operated in existing stabilized mounts in the RC-130 aircraft. The spectrometers and color reference cameras are IMC integrated and synchronized with the multiband camera by a common intervalometer. This instrument also serves as the data link with the spectrometer recordings permitting a synchronized signal to be recorded on the magnetic tape.

Multiband Camera

The Itek nine-lens multiband camera, a unique research tool for obtaining spectral photographic data, is shown in Figure 1. Camera data are presented in Table 1.

The multiband camera obtains photographic coverage from 0.4 to 0.9 microns. The coverage is subdivided by the use of nine matched lenses with different filters to take nine simultaneous exposures of the same identical ground area. Each of the resultant nine photographs taken during one exposure is of matched image size uniform with 0.001 inch. Resolution is from 20 to 30 lines per millimeter. Six of the exposures are on two rolls of 70-mm. panchromatic film and three exposures are on one roll of 70-mm. infrared film. Eight of the exposures represent signatures in eight different narrowband portions of the spectrum. The ninth exposure is the full sensitivity range of the IR film. The sensitivity of panchromatic and infrared film plotted against the eight filter bands is shown in Figure 3. The filters used with each lens are shown in Table 2.

The camera body is a one-piece aluminum

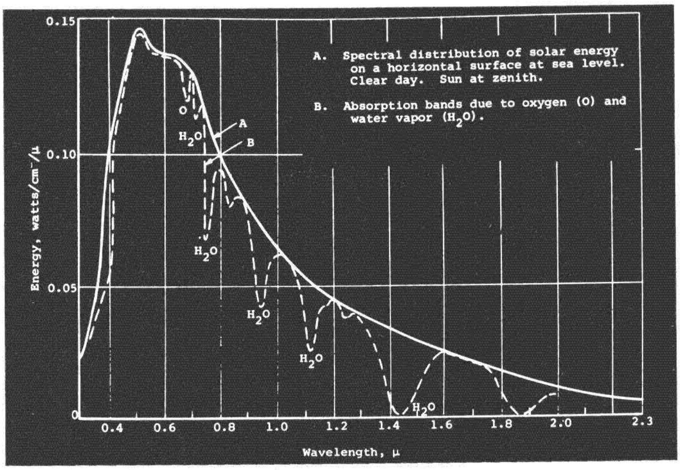


FIG. 2. Solar energy expected on the ground.

alloy sand casting with the external configuration designed to fit the ART-25 stabilized mount. The body is fitted with nine 6-inch lenses, light baffles, frame number counter, and magazine drive assembly.

The magazine drive assembly consists of a DC driven motor, a worm gear housing and a coupling to match the *A 9-B* magazine drive coupling. Cycle time is $1\frac{1}{2}$ to 2 seconds, depending on film load and supply voltage. The frame counters are operated by an overhead rocker arm which is coupled to the magazine drive motor. The count can be viewed from outside the camera body and can be reset to zero with a single stroke. Lucite tabs with numbers are located on each of the frames in a staggered manner so that each frame number will show when films are superimposed.

The nine 6-inch f/2.8 Schneider Xenotar matched lenses are mounted to the camera body casting with shims to adjust focal distance.

The camera magazine is an *A 9-B* image motion compensation magazine modified to permit use of three 70-mm. films instead of $9\frac{1}{2}$-inch film.

The shutter is made up of three main and three capping curtains operating as a single unit. The camera is operated at a shutter speed of 1/50 second because of the large exposure factors necessary to obtain the sharp cutoffs between the eight filter bands.

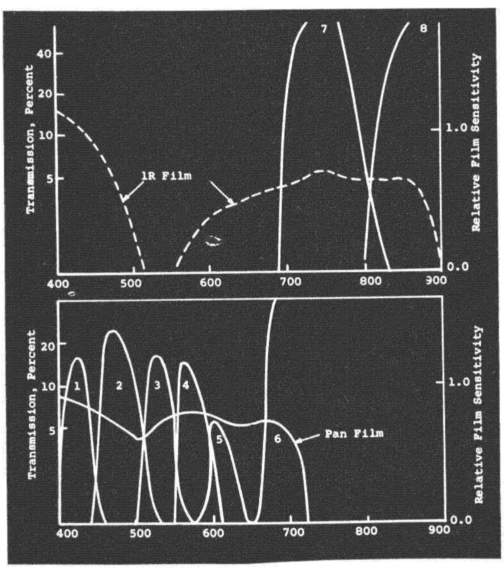


FIG. 3. Filter transmission and film sensitivity versus wavelength.

SEVENTY-MILLIMETER FRAME CAMERAS

The program also uses two 70-mm. reconnaissance cameras with 100-foot magazines

TABLE 1

MULTIBAND CAMERA DATA

Lens	Nine 6-inch f/2.8 Schneider Xenotar matched lenses
Film Type	Two rolls of 70 mm. Plus X Aerographic, one roll 70 mm. Infrared Aerographic
Frame format	Nine frames each $2\frac{1}{4}$ by $2\frac{1}{4}$ inches
Exposure Technique	Three exposures on each roll of film
Shutter system	Three parallel focal plane shutters of three slits each so as to expose all nine frames simultaneously
IMC	Modified A-9-B magazine with film drive image motion compensation.

to expose aerial Ektachrome and Camouflage Detection Film.

The Schneider Xenotar 6-inch f/2.8 lenses are used with these cameras to match the multiband camera. The first camera is a standard model with 1/500-sec. exposure for use with Ektachrome film. The second camera was modified to 1/300-sec. exposure to use camouflage detection film. A third camera with 1/500-sec. exposure serves as a backup unit. A frame counter which was designed to fit on the back of each of the film magazines can be reset from the control console and the count can be checked visually.

ABSTRACT: *A unique airborne spectral camera and data reduction system has been developed for reconnaissance of terrain surfaces and especially for detecting manifestations of underground nuclear test activity. The system operates in the 0.35 to 5.0 micron region of the visible and near-infrared spectrum. The airborne system consists of a nine-lens multiband camera, associated color reference cameras, a dual spectrometer system, cartographic camera, and skylight recording camera, flown in a C-130 aircraft. Specialized color enhancement and printing techniques emphasize the spectral reflectivity differences on the film to enable analysis of surface effects. Ground spectral data are collected to assist the interpretation of aerial imagery significance. Photointerpretation of vegetation and geologic conditions by simultaneous photography in narrow spectral regions will be advanced by this system.*

AIRBORNE SPECTROMETER SYSTEM

The airborne spectrometer consists of two instruments, with a fifteen degree field of view. One of the instruments uses a cadmium selenide photoresistive detector with a useful response in the spectral range of 0.35 to .94 microns. The other instrument uses a lead sulfide detector with a useful response in the spectral range of 0.8 to 3.5 microns. The crown glass window in the RC-130 limits the long wave response of this instrument to approximately 2.8 microns.

The spectrometers use the Michelson Interferometer principle to obtain much greater sensitivity than conventional rocking grating spectrometers. They are small, light in weight, have rapid scan capability, and can be used with various detectors to cover a broad spectral range. Since the spectrometers are very sensitive to vibration, the spectrometer heads are suspended in a rubber membrane basket to eliminate high frequency vibration, and padded to dampen the gross lateral and vertical movement. Image motion compensation is provided by a rocking mirror. The spectrometers are bore-sighted to coincide with the optical axis of the camera system.

In flight the spectrometer data are recorded and stored on magnetic tape, with a binary address corresponding to the multiband exposure. These data are converted to $X-Y$ graphic spectral plots by the use of a sweeping wave analyzer. Development is now underway for analog to digital signal conversion and subsequent statistical correlation and automatic computing of spectral ratios by a digital computer.

SKYLIGHT RECORDING CAMERA

An additional camera has been modified to provide a means for making comparative evaluation of light level and relative spectral energy from film exposed on different days and is used to calibrate signature and color technique. The camera fits into the RC-130 sextant mount and incorporates an integrating sphere and light pipe instead of a lens. The incident illumination is transmitted through the eight multiband filters onto panchromatic and IR film.

TABLE 2

MULTIBAND CAMERA SPECTRAL BANDS

Lens No.	*Bandwidth* ($m\mu$)	*Filters Used*
1	400–500	Wratten 2B+35+38A
2	450–510	Wratten 3+47
3	520–550	Wratten 15+65
4	550–600	Wratten 57+12+Balzers 155/116
5	590–640	Wratten 90+24+Optics Tech. Interference
6	670–720	Wratten 36+12
7	700–810	Wratten 89B+Balzers 455/141
8	810–900	Wratten 87C
9	Full Sensitivity range of IR film	

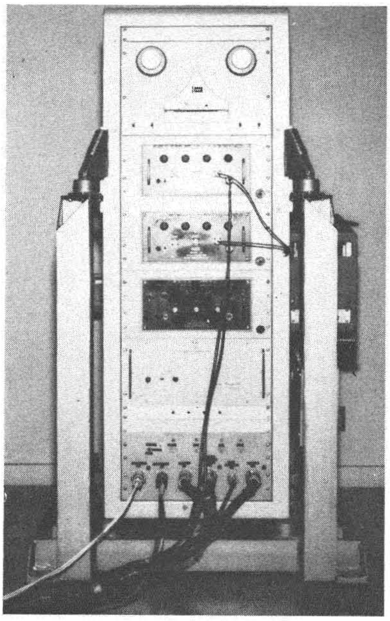


FIG. 4. Spectral system control console.

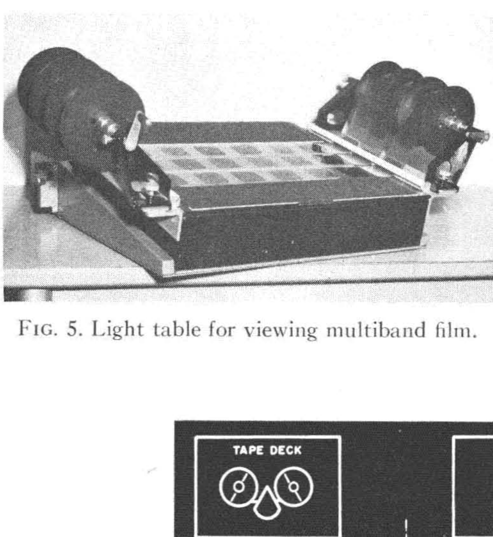


FIG. 5. Light table for viewing multiband film.

Control Console and System

The control console shown in Figure 4 contains equipment necessary for the manual control and monitoring of the airborne sensors. A spectrometer monitoring scope, spectrometer monitoring selecter, and an IMC monitor meter have been added to the control panel in the console. The four channel tape recorder, spectrometer controls, binary counter, all of which can be pre-set, are housed in the rear of the console along with the cable connectors.

The console, which weighs approximately 500 pounds, is on casters and can be rolled into the RC-130 and secured to the aircraft deck.

Data Handling System

The reflected energy from the earth's surface is recorded by the airborne photographic and spectrometer systems and techniques have been devised to systematically handle the acquired flight data. The data that are subject to analysis are: original color and black and white photography, spectral signatures derived from the multiband photography, color derivatives and spectrograms.

Photographic Analysis

The multiband photography is examined on a modified Richardson Light Table shown in Figure 5 so that the nine photographs from one exposure can be examined together. The aerial ektachrome and camouflage detection color film are examined on light tables using the Bausch and Lomb Stereozoom Microscope. The color films are compared with the black and white photography in performing photoanalysis and selecting frames for color

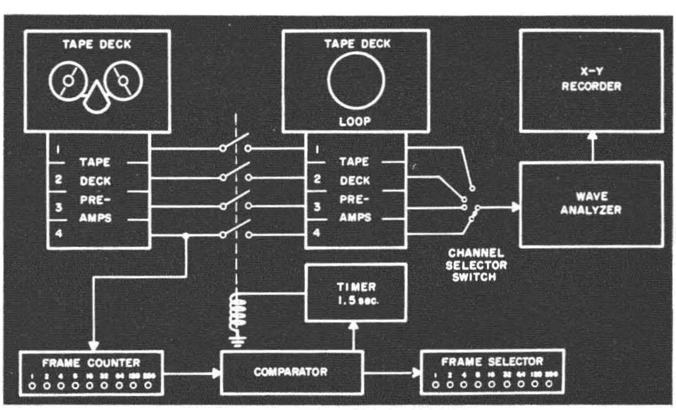


FIG. 6. Block diagram of analog method used for production of spectrographs.

FIG. 7. Multiband panel showing wide tonal variation of crops in differing spectral regions.

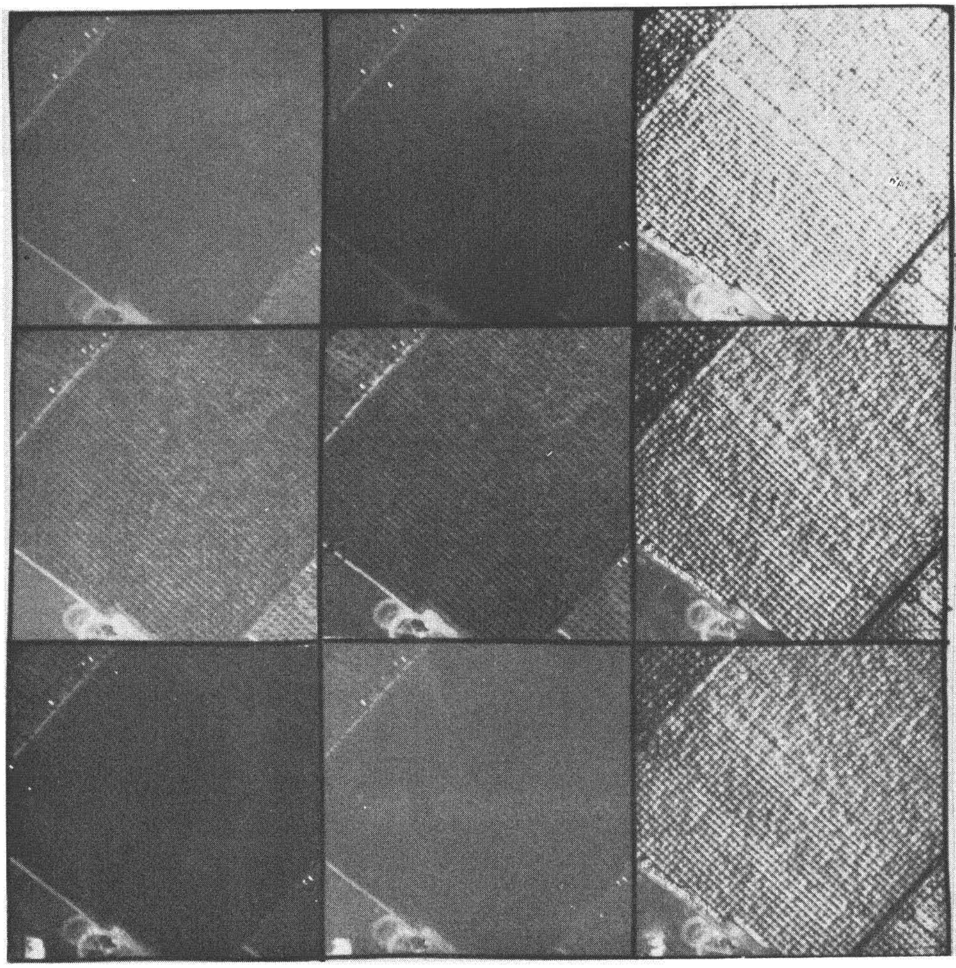


FIG. 8. Crown pattern details in the orchard are distinct in IR bands 7, 8 and 9, but less clear in bands 1, 2, 3, 5 and 6. Human activity is evident in band 4 under the trees (less clearly in band 3 also) but not in the other bands.

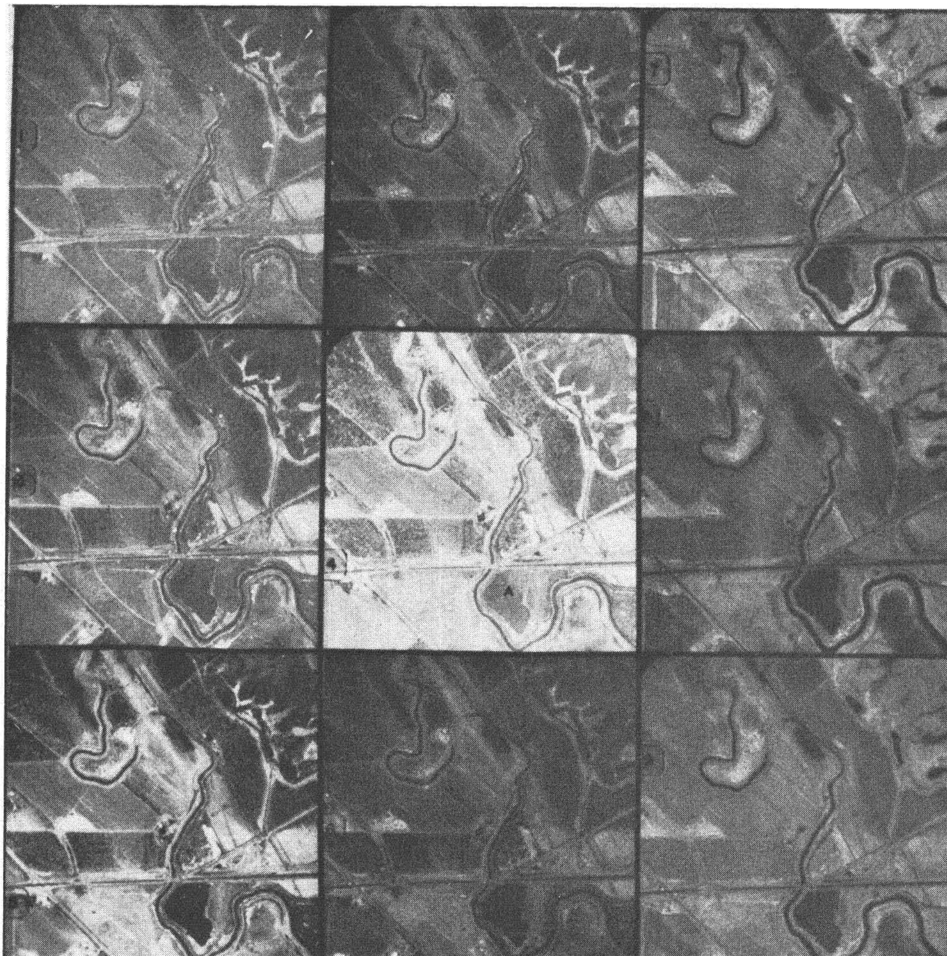


FIG. 9. Several differences in appearance are evident between ponds and along a flowing stream. Shallow water and sessile vegetation shows at *A* in bands 3 and 4. The dark-toned "fingers" in IR bands 7, 8 and 9, extending from the ponds toward the upper right, indicate springs and seeps. (1/20,000 scale).

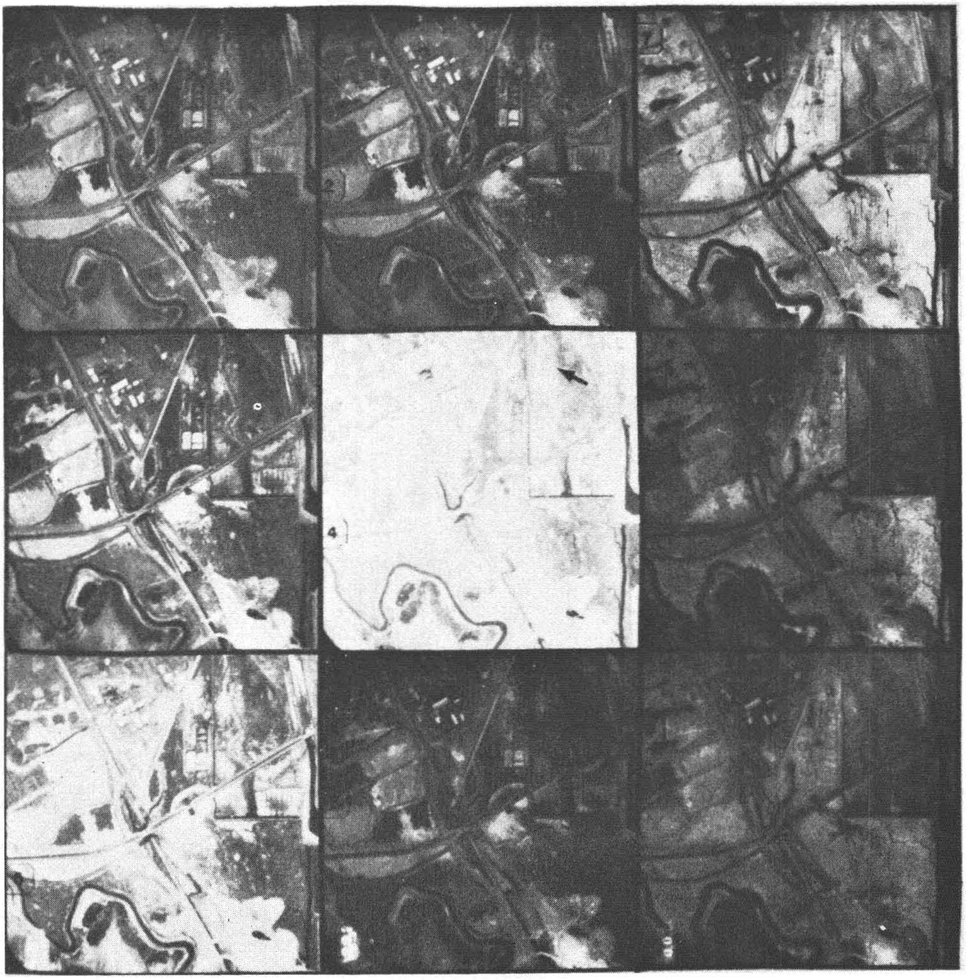


FIG. 10. Some details of bridge and highway construction are more evident in each of the nine frames. The old building foundation at the head of the arrow is more distinct in some frames than in others.

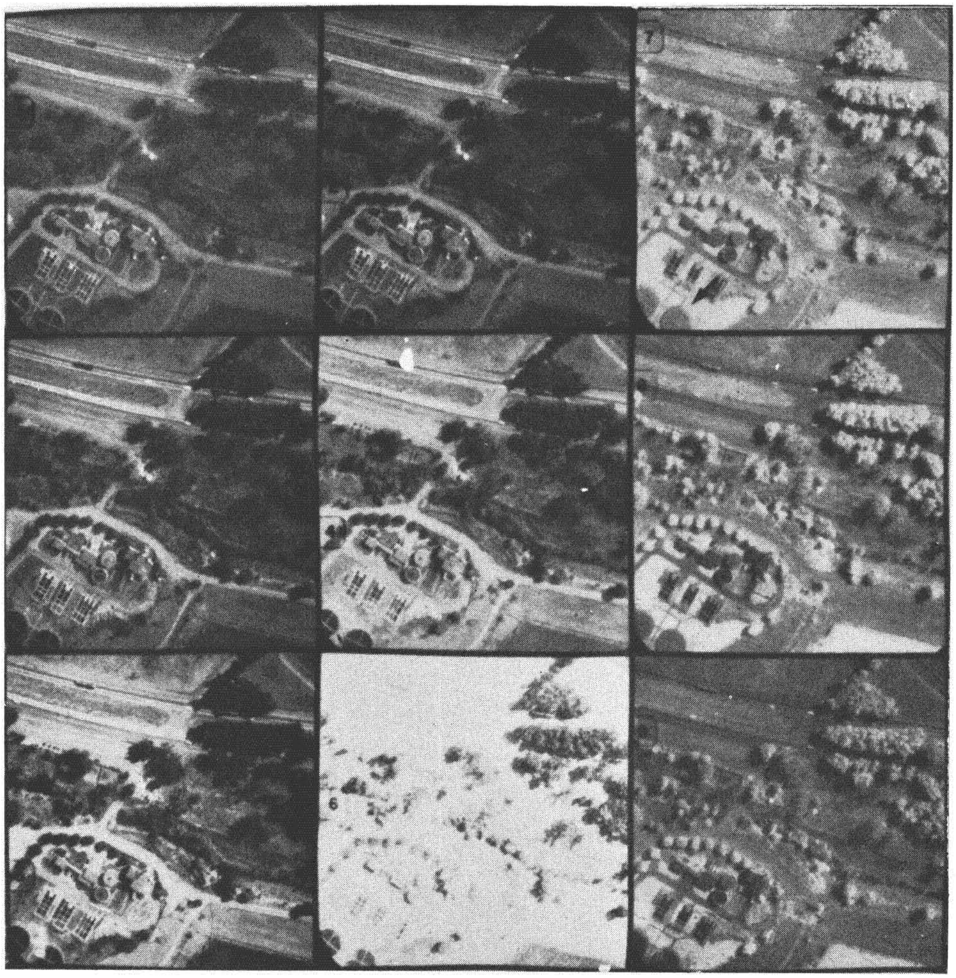


FIG. 11. Some agent, probably biological, reflects or emits photographic infrared from the beds of trickling filters (secondary sewage treatment plants). This condition might possibly enable a rapid assessment of the operating efficiency of sewage treatment plants.

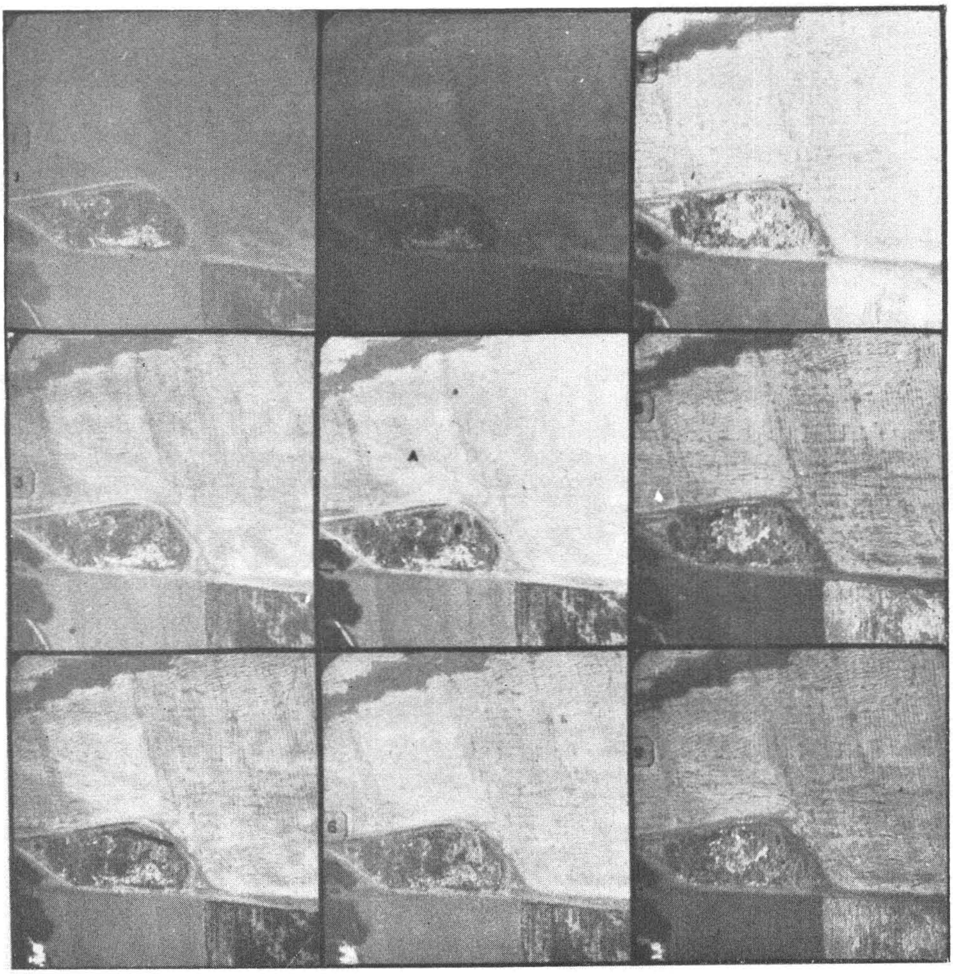


FIG. 12. Distinct soil and vegetation variations shown in visible and infrared photographs.

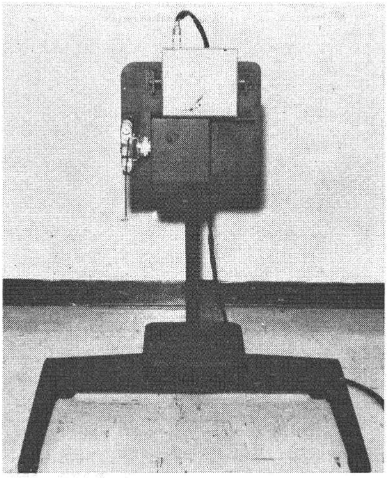


FIG. 13. Optical unit for ground spectrometer use.

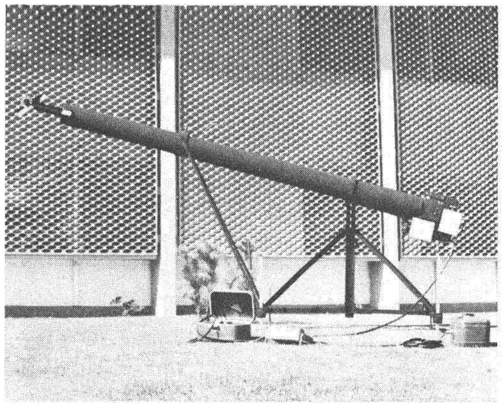


FIG. 14. Boom-mirror mounting of ground spectrometer.

enhancement and for spectrometer data reduction.

The 70-mm. frame photography is also useful in photogeologic interpretation supplementing the cartographic photography. The IR (bands 7 and 8) is useful where moisture differences in soil are helpful in bringing out surface features. Enlargements are made from selected bands to aid interpretation.

The small frame format, limited area coverage of each frame, and large number of frames of photography to be analyzed make the use of the nine-lens camera presently valuable to research programs and pilot studies. An operational system might only require photography from a lesser number of selected band widths to provide the information and area coverage required.

Spectral Signature Technique

The spectral signature techique is simply that the calibrated data from the output of the spectral camera can be used to generate a spectrogram for any object photographed. The wavelength resolution is determined by the bandwidth of the filters used. Data from the skylight recording camera is used to establish the relationship of object brightness to density for each of the bands. Density measurements are obtained from the film with the $X-Y$ co-ordinate densitometer. The relative brightness values for each band will be used in drawing a spectogram for the selected object.

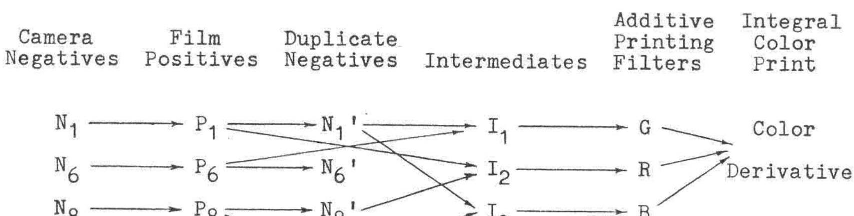
Spectral Data Reduction and Analysis

Figure 6 is a block diagram of the method used for the production of spectrographs. An equipment design and computer program is currently under development to provide an effective means of statistically reducing the large volume of data provided by the spectrometers accurately and economically.

Color Enhancement

A color separation technique is used to enhance the tonal differences between objects or areas imaged in the multiband photography. Selected frames from the eight bands produced in the multiband camera provide the tonal values necessary to employ a color separation system. Reflectance data from the ground spectrometer system provide information on the spectral bands that can be used to enhance reflectance changes in plants or earth

TABLE 3
THE COLOR ENHANCEMENT PROCESS



surface due to physical manifestations.

Photographic methods are currently being used in performing color enhancement. The process is difficult and time-consuming but is expected to demonstrate the feasibility and usefulness of the technique. Applying color enhancement in an operational system will utilize electronic techniques for rapid scanning and analysis and more sophisticated photographic laboratory methods for the production of materials required for reporting purposes.

The following discussion describes the color enhancement process, illustrated in Table 3. The multiband exposure is examined to select three frames as inputs for color enhancement. In this illustration, frames 1 (band 400–450 mμ), 6 (band 650–700 mμ), and 8 (band 800–900 mμ) were selected because of greatest visual differences.

The process is carried out as follows:

Step 1. Film chip positives are exposed by contact on the Roll-To-Chip printer, and developed to a gamma of 0.7.

Step 2. These positives are registered and punched in the Registration Punch.

Step 3. The positives of bands 1 and 8 are printed by contact into pre-punched film in the Registration Printer, and developed to a gamma of 1.0, to produce duplicate negatives.

Step 4. The positives and negatives are printed subtractively (superimposed) in registration onto prepunched film in the Registration Printer to form intermediates. Each intermediate is made from the superimposition of one positive and one negative each from a different band. One intermediate is printed from each of the following combinations:

I_1 from $N_1'+P_6$

I_2 from $N_8'+P_1$

I_3 from $N_1'+P_8$

Step 5. The intermediates made in Step 4 are used in making the final integral print on Ektacolor Print film. Each intermediate is printed additively in the registration printer so that the image of each is transferred to only one of the color controlling layers of the Color Print.

I_1 is printed from a green filter to form an image in the magenta layer

I_2 is printed with a blue filter to form an image in the yellow layer

I_3 is printed with a red filter to form an image in the cyan layer.

These images, when printed on a single tripack film constitute the final color enhancement, which, being a transparency, can be used for viewing or reproduction.

The intermediates represent differences of reflectance between bands, so these color differences are what is represented. Where no color differences occur, the negatives and positives cancel, so no color shows on the final enhancement. Increases in the original tonal contrast of 10 per cent for normal color film to 60 per cent in the final color derivative product of the multiband camera have been produced.

Representative samples of multiband photography are given in Figures 7 through 12.

Ground Spectrometer Data Collection

A supplementary system of portable, self-contained ground spectral reflectance measuring instruments has been developed to provide useful data to enhance the interpretation of the airborne spectral imagery. The system consists of the same pair of spectrometer units as used in the aircraft with battery-powered photographic and electronic recording equipment.

An optical unit shown in Figure 13 was designed to allow the two spectrometer heads and an associated recording camera to view along the same optical axis. The spectrum to be measured can be sequentially viewed by each of the two spectrometer heads and the camera by rotating mirrors in the optical unit.

Standardization of solar light intensity and calibration is accomplished before each reading by a spectrometer reading of a vapor-deposited aluminized glass cloth reflectance standard panel.

Present mounting configuration shown in Figure 14 uses a 10 foot aluminum boom with a mirror mounted at the top end. The mirror is adjusted to allow the spectrometer to look at the ground area directly below. In this manner vegetation up to 10 feet in height can be viewed at rates up to 60 points per 5 hour day.

Surface effects of changes in moisture content, vegetation conditions, soil density, subsidence, deposition of dust, etc. can thus be detected by skilled photointerpreters from the relative brightness and color difference of any such natural or artificial anomalies appearing on the resulting imagery. With test flights over areas having detailed ground property knowledge a catalog of "keys" can readily be developed for use in remote areas.

The application of multiband spectral reconnaissance has obvious advantages over black-and-white or color aerial photography in detecting and recording the more subtle changes of surface conditions occurring seasonally in nature or as a result of military or cultural activity. The present system has been used at altitudes below 10,000 feet, but there is no theoretical limit to its altitude effectiveness.

END.