

PROTOTYPE ACTIVE SCANNER FOR NIGHTTIMEOIL SPILL MAPPING AND CLASSIFICATION

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ABSTRACT

A prototype, active, aerial scanner system has been constructed for nighttime water pollution detection and nighttime multispectral imaging of the ground.

An arc lamp is used to produce the transmitted light and four detector channels provide a multispectral measurement capability. The feasibility of the design concept has been demonstrated by laboratory and flight tests of the prototype system.

1. BACKGROUND

Battelle-Northwest has constructed and operated aerial optical-mechanical scanner systems since 1968. The principal applications of these systems have been thermal infrared (IR) and tracer dye studies of power plant outfalls and multispectral geological surveys. These applications all involved the use of passive scanner systems which depend on sunlight for their operation. In recent years, it has been evident that an active multispectral scanner (that is, one which contains its own light source) would be useful in several remote sensing applications. For example, by stimulating and detecting fluorescent emissions, a system with an internal ultraviolet (UV) light source could potentially detect, map, and classify spills of oils or other fluorescent chemicals at night. Further, passive multispectral measurements and classifications of vegetation and other ground materials are often corrupted by shadows which are seen by the sensor. Because only backscattered light is detected by an active system, active measurements are free of shadow effects. Finally, effects due to variations in the direction and intensity of the illumination tend to be reduced with an active system.

With this motivation we began the development of an active multispectral scanner. The attractive possibility of using lasers to illuminate the ground or water and to stimulate fluorescence was examined, but was rejected because our objective was to develop a small, relatively inexpensive system that could be operated in a light twin-engine aircraft. This objective seemed to be incompatible with the use of lasers at this time. Xenon and mercury-xenon arc lamps were therefore adopted as alternative light sources.

The first flight tests of our prototype active scanner system were conducted in November, 1974. Those tests involved the successful detection and mapping of oil slicks and rhodamine dye in water. Since that time, several other flight tests and related laboratory measurements have been made. Some of the results of those tests are presented below.

2. SCANNER DESIGN

The basic design of the prototype active scanner is shown in Figure 1. As shown in the diagram, the scanner utilizes two reflecting telescopes with a common field of view which is swept across the ground by means of rotating mirrors. This field of view, which is a circular or elliptical spot, is illuminated for nighttime operation by an arc lamp placed at the focal point of the telescope shown on the left side of the scanner. Light reflected or emitted by materials on the ground or on a water surface is focused on the tip of a fiber optics bundle placed at the focal point of the second telescope. The received light is then transmitted via the fiber optics into the detector assembly where it is separated into four spectral bands and detected by photomultiplier tubes.

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The scanner can be operated in three modes: 1) An active mode for nighttime imaging of fluorescent materials. In this mode, the UV lines of a mercury-xenon arc lamp are projected onto the ground. The output of the lamp is filtered so that only the UV portion of its spectrum is transmitted. The UV light is blocked in the detectors so that they respond only to the light emitted by the fluorescent material. 2) An active mode for nighttime multispectral imaging of the ground. A xenon arc lamp is used without a source filter to illuminate the field of view. The xenon arc lamp emits a broad continuum of light in the UV to near IR spectral range. 3) The passive mode. With the arc lamp off, the scanner functions as a normal, passive, multispectral scanner.

The outputs of the four channels and a sync signal are illustrated in Figure 1. The sync signal is derived from an optical sensor which detects a timing mark on the rim of the rotating mirror block. The video and sync signals, together with a roll signal produced by a gyro in the nose of the aircraft, are amplified and recorded in analog form on a fourteen-track Sangamo Sabre III tape recorder.

For flight operations, the scanner is mounted on the underside of a Cessna 320 aircraft. It scans in a plane normal to the aircraft flight path and extending 60° to either side of nadir. The relationship of the scanning system to the ground is illustrated in the lower part of Figure 1.

The mercury-xenon and xenon arc lamps used in the active scanner operate at powers of 600 and 700 watts, respectively. The operating voltages and currents are directly compatible with 28-volt aircraft electrical systems. The output spectra of the arc lamps are shown in Figure 2. The transmission curve of the glass filter used in the fluorescence mode is also shown. The emission lines within the UV pass band of the filter contain approximately 30% of the optical energy emitted by the mercury-xenon lamp.

Four photomultiplier tubes with band-pass filters are used to obtain measurements in four spectral bands. A four-branch light guide is a straightforward means of splitting the light collected by the receiver telescope into four equal parts and for transmitting the light to the detectors. However, at least 75% of the light is lost in this method.

An alternative method which offers a potential for better efficiency has been devised. A bifurcated light guide is used to transmit light from the receiver telescope to the interior of a pentagonal cavity. The light enters through a block on one side of the pentagon. An interference filter is mounted flush with the interior wall of each of the other four blocks. The two middle filters in the pentagon are directly illuminated by the two branches of the fiber optics light guide. Wavelengths within the passbands of these two filters are transmitted through the filters and are detected by the photomultiplier tubes mounted directly behind the filters. Wavelengths outside the passbands of the middle filters are reflected toward the other two filters where additional fractions are transmitted and detected. The reflectivity of each of the filters is in the range 80-90% at wavelengths outside its passband. Additional efficiency is derived from reflections within the cavity. Small lenses at the entry ports focus the light on the filters, and the inner surfaces of the top and bottom caps are aluminized glass mirrors. The realized gain in efficiency of this system in comparison with a simple four-branch light guide arrangement has been approximately 50%.

For fluorescence measurements, the optical bandpass characteristics of the filters are selected to cover the range 400-600 nm in approximately four equal parts. For multispectral reflectance imaging of the ground, the filters cover the range 300-900 nm. Figure 2 shows the spectral bands of the detectors in relationship to the output spectra.

The spectral resolution of the prototype scanner is determined primarily by the angular divergence of the output light beam, approximately 10 milliradians. If the aircraft is flying 300 m above the ground, the diameter of the illuminated area at any instant is approximately 3 m.

3. RESULTS

In the first nighttime flight tests of the prototype active scanner system, a two-gallon slick of motor oil was imaged from an altitude of 300 m. The estimated average thickness of the slick was 40 μm . The left side of Figure 6 shows three intensity-sliced active images of the oil slick. This sequence shows the spreading of the slick over a period of approximately 20 minutes. In another test, Rhodamine B, a fluorescent tracer dye, was imaged from an altitude of 300 m at a concentration of less than 1 ppm.

In August, 1975, the scanner was used in a unique hydraulic model study conducted jointly by the University of California at Berkeley and Battelle-Northwest for the Pacific Gas and Electric Company. The purpose of this study was to examine the behavior of a thermal plume produced by the discharge of cooling water from a nuclear reactor. The active scanner was mounted on a large crane approximately 7 m above the water surface in the test basin. As the crane traversed the basin, two-dimensional tracer dye imagery was acquired. This imagery graphically and quantitatively displayed the dynamic behavior of the plume under the influence of waves and currents in the model sea. Rhodamine B concentrations of less than 5 ppb were readily mapped in scan angles up to $\pm 55^\circ$ and slant ranges up to 12 m. Figure 3 is a set of four images which shows an example of the movement of dye in the plume.

Figure 5 illustrates the results of a flight over a test pond containing a slick of Valvoline 85W140 gear oil. The photograph is an intensity-sliced image of the test pond which was approximately 10 m wide and 20 m long. Oil that had leaked out of the pond onto an underlying concrete slab is visible both above and below the pond. Figure 5 shows a comparison between the fluorescence spectrum of the oil as measured by the scanner in four spectral bands and the spectrum of the oil as measured by a spectrophotometer in the laboratory.

Scanner images of the natural oil seeps in the Santa Barbara Channel were obtained in the passive mode during daylight hours. Good high contrast images of the oil slicks were obtained at altitudes up to 3000 m, the maximum altitude flown.

An example of active, nighttime, reflectance imagery is shown in the right half of Figure 6. This image was produced from bands 1, 2, and 4 (see Figure 2). It is, therefore, similar in spectral character to a normal infrared photograph in which green vegetation is imaged in red. The specularly reflected transmitted light beam is shown where the flight path crossed the Columbia River. In the fluorescence mode, this component is filtered out in the detectors and is not seen.

4. DISCUSSION

A series of laboratory measurements of arc lamp-stimulated oil spectra was conducted to help in assessing the sensitivity of the active scanner for oil spill detection. Fluorescence spectra were measured for 14 crude and refined oils and five other chemicals. These measurements together with flight test results have shown that an operational oil spill mapping and classification capability will be attainable with the construction of a second generation scanner.

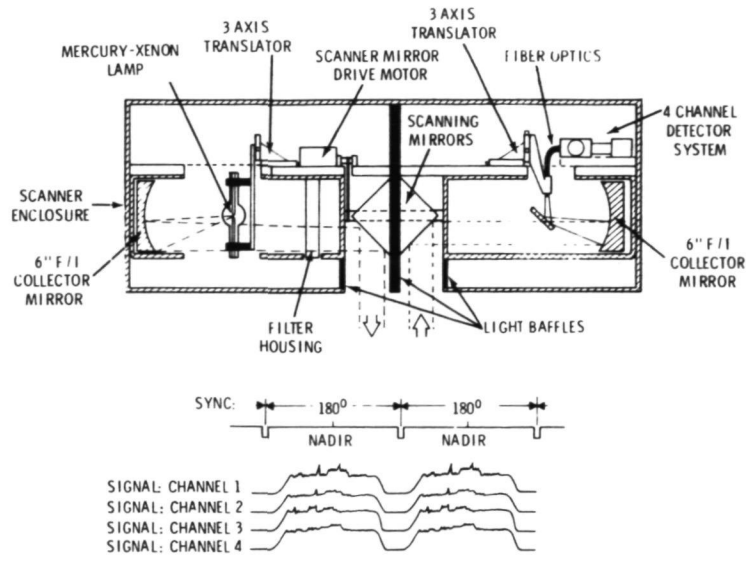
The design concept also appears to be practicable for multispectral imaging of the ground and for spectral classification of vegetation and other ground materials.

At this time we plan to construct a second generation, or operational, version of this scanner and expect to achieve an improvement in sensitivity of at least a factor of 100.

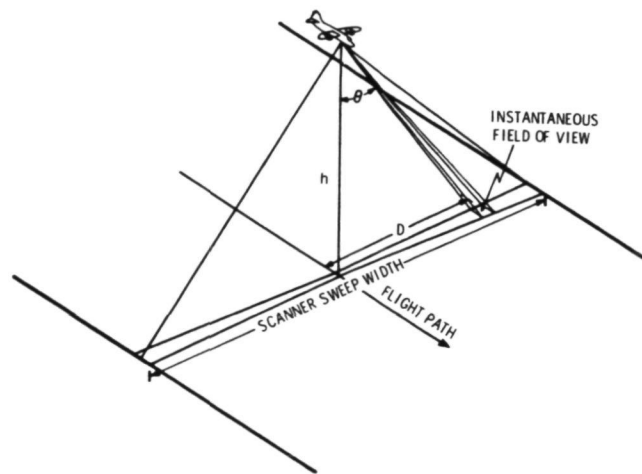
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SCHEMATIC OF OPTICAL-MECHANICAL ACTIVE SCANNER SYSTEM AND SIGNALS
PRODUCED BY THE DETECTORS



IMAGING SYSTEM RELATIONSHIP TO THE GROUND

FIGURE 1.

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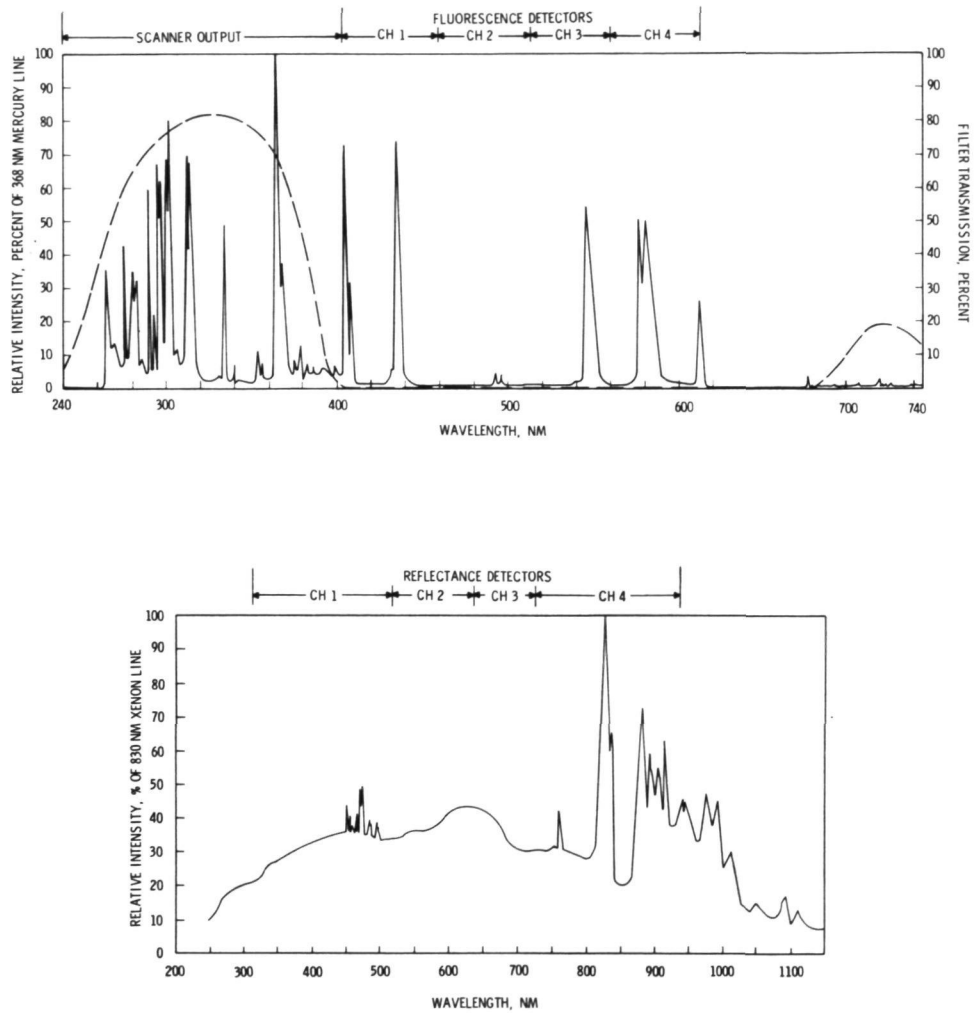


FIGURE 2. ARC LAMP SPECTRA. The upper graph is the spectrum of the mercury-xenon arc lamp. The dashed line is the transmission curve for the UV bandpass filter. The lower graph is the xenon arc lamp spectrum. The wavelengths of the detector bands are also shown.

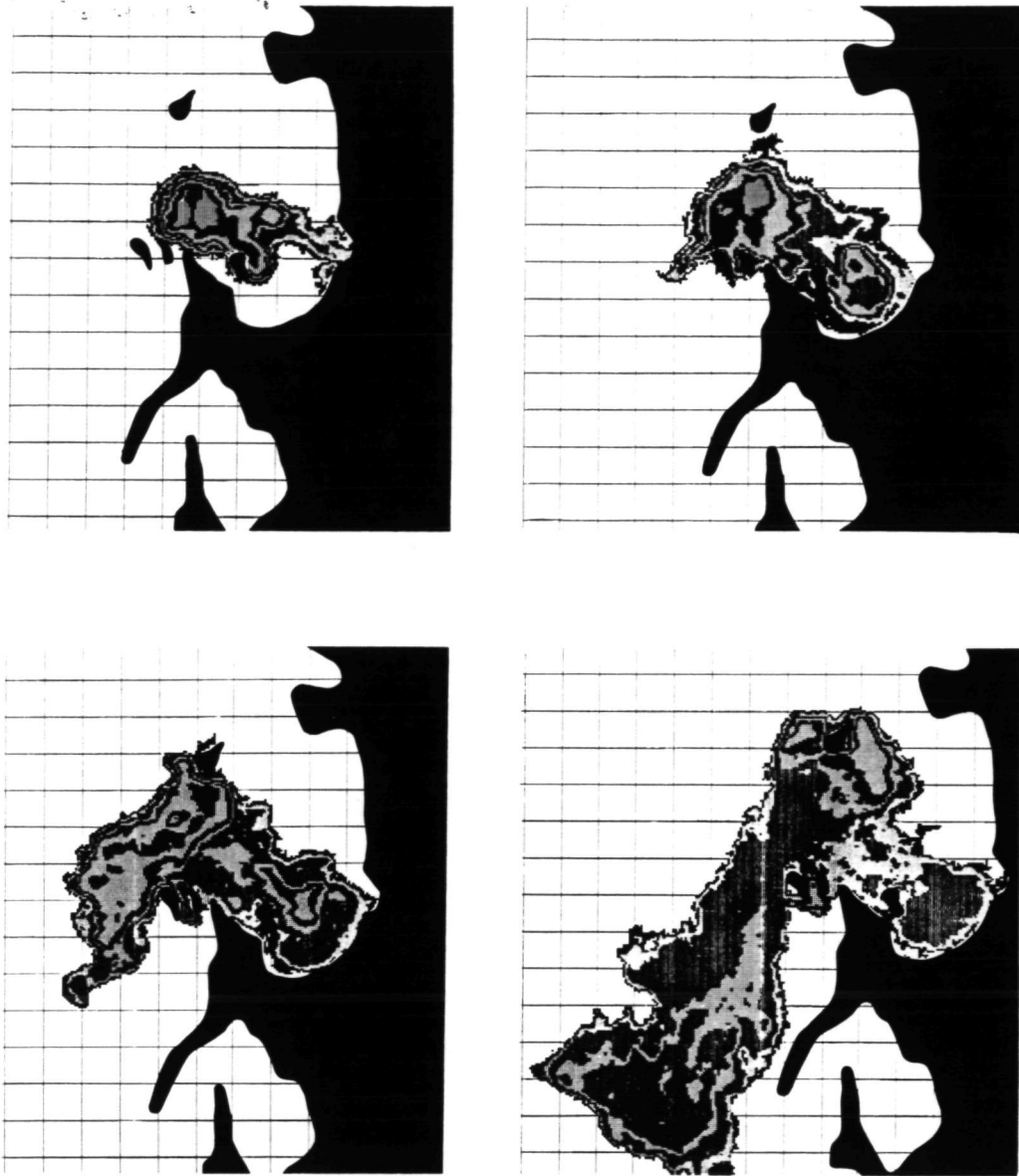


FIGURE 3: HYRAULIC MODEL TEST SEQUENCE. The four pictures show the movement of rhodamine tracer dye in the 1:75 scale cooling water discharge plume of the Diablo Canyon nuclear reactors. Elapsed time is approximately 10 minutes.

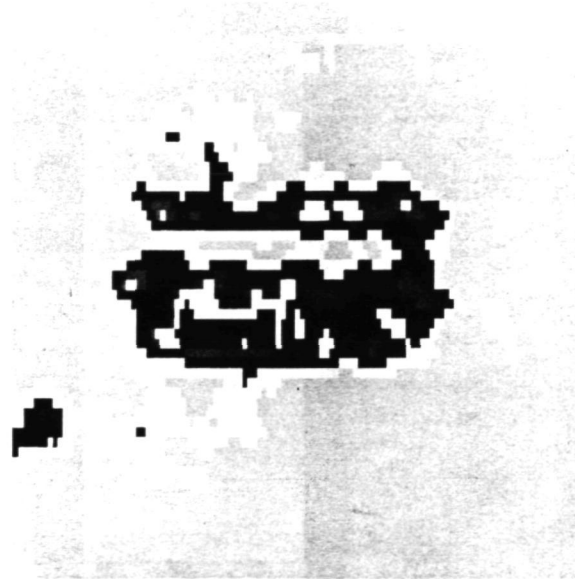


FIGURE 4. OIL IN TEST POND. Intensity sliced active nighttime imagery collected over a test pond. The oil is Valvoline 85w140 gear oil.

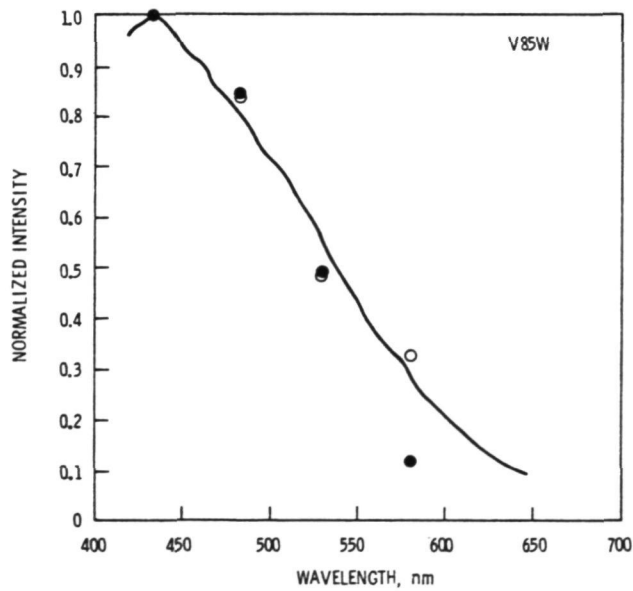


FIGURE 5. OIL FLUORESCENCE SPECTRA. Dots are scanner data measured at an altitude of 110 m. Open circles are scanner data measured at 75 m. Line is laboratory spectrophotometer measurement.



Figure 6. ACTIVE AERIAL SCANNER IMAGERY. The photograph on the left is a series of three nighttime fluorescence images showing the spreading of a 2-gallon oil slick. The scale is approximately 1 cm = 25 m. The picture on the right is a 3-band active image collected at night from an altitude of 300 m. The scale is approximately 1 cm = 200 m.