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AIRBORNE INFRARED LINE SCANNERS FOR FOREST FIRE SURVEILLANCE

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ABSTRACT

Airborne infrared line-scanning systems for detecting latent forest fires and for determining the size and characteristics of conflagrations when smoke or darkness prevents obtaining this information visually have been developed and tested. A prototype system is operational in the U.S.D.A. Forest Service fire suppression organization; its usefulness in helping suppress large fires is well established. During 1967, a fire detection system was flight-tested; more than 600 targets were detected and their positions plotted. A unique target discrimination module for automatically identifying hot targets was developed and evaluated. In 1968 system performance was improved by including a second detector to permit identification of hot targets by real-time analysis of spectral signatures. This system is now undergoing tests of operational suitability in an 8,000-square-mile area in western Montana. The equipment design, performance characteristics,and operational methodology are discussed, along with future display and recording requirements.

INTRODUCTION

Every year in this country, forest fires -- more than 100,000 of them -- (U.S.D.A. Forest Service 1940-68) blacken an area larger than the State of New Jersey. The annual toll in terms of living things and natural resources, to say nothing of the aesthetic loss, is incalculable. Devastation of forest lands reaches approximately the same shocking proportions year after year, but it could be reduced dramatically if small fires could be found and suppressed before they spread.

The fire detection system now operated by forest protection agencies and private landowners is far flung and expensive, but it is inadequate. It consists of 3,500 lookout towers and 400 light aircraft and operates during periods when fire danger is high -- normally 3 to 4 months in most parts of the country (Zimmerman 1969). As do all visual detection systems, it relies on someone seeing the smoke column above a fire. Reliance on visual detection is but one of the shortcomings of such a system. Visibility can be limited by smoke from other fires, by darkness, haze, or smog. Moreover, most latent fires produce little smoke and are extremely difficult to see.

Forest fire detection costs more than $10 million annually, yet organized detection systems spot less than 30 percent of the fires — the remainder are reported by the public. Significantly, 40 percent of the fires spotted by organized systems have burned for more than 8 hours before detection (Barrows 1951).

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The cost of forest fire suppression exceeds $300 million annually. If this figure and forest fire damage are to be reduced, we must improve our detection system significantly.[2]

AIRBORNE INFRARED FIRE DETECTION

In 1962, the U.S. Department of Agriculture, Forest Service, inaugurated Project Fire Scan to study the application of airborne infrared (IR) line scanners in detection of latent forest fires and in mapping large fires when it is impossible to obtain this information visually. An economically feasible system must be capable of patrolling extensive areas at low cost (visual air patrol operates for 6¢ per square mile). Rate of coverage for an airborne infrared detection system depends on aircraft speed, altitude, and scan angle. The usable altitude is constrained by cloud cover, system angular resolution, and thermal sensitivity. The usable scan angle is constrained by the screening effect of the forest overstory.

We made extensive airborne and ground-based measurements to determine the relation between detection probability, scan angle, timber overstory characteristics, and fire size (Wilson 1968). The highlights of these tests are shown in figure 1. A scan angle of up to 60° from the nadir provides an acceptably high probability of detection for most timber types of interest.

Currently available IR line scanners, with angular resolution of 1 milliradian and temperature sensitivity of 1° C., provide adequate performance at altitudes ranging from 15,000 to 25,000 feet above terrain. Frequently, it is possible to conduct fire detection missions at altitudes below 15,000 feet when cloud strata prevent higher altitude operations. This consideration has dictated the choice of a turboprop aircraft rather than a jet, and limits our maximum groundspeed to approximately 300 knots. Scanning 120° at 15,000 feet provides 10-mile-wide coverage.

A turboprop aircraft in the light executive category is capable of patrolling 8,000 square miles in a 4- to 5-hour flight. We need to interpret the imagery in near-real time. Small fire targets appear as points equal in size to one resolution element (0.002-inch diameter). The efficiency of an interpreter in detecting these small targets at the rate the imagery is being produced is extremely low. Fortunately, the targets of interest exhibit recognizable spectral and spatial signatures. By making use of these characteristics we have been able to recognize targets electronically and to cue the operator by means of a mark at the edge of the record and a bright spot next to the actual target (Fig. 2).

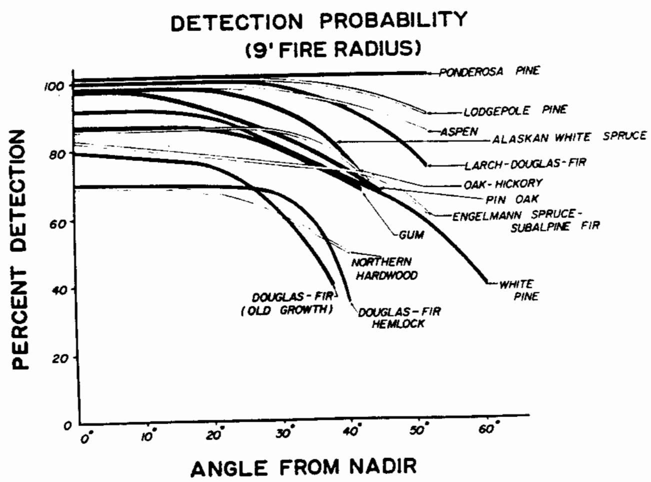

Figure 1.—Infrared fire detection probability classes (9-foot fire radius).

Figure 2.—Nighttime imagery, 23,000 feet m.s.l. Fire targets (circled) marked by TDM. I, TDM indicators; and II, 1-mile markers.

[2] Statistics quoted in this section refer to forest lands under Federal, State, and private ownership.

The system shown in block diagram (Fig. 3) consists of a conventional line scanner with two detectors — mercury-doped germanium (HgGe, 8- to 14-micron) to sense the terrain signal, and indium antimonide (InSb,3- to 6-micron) to sense terrain and peak radiance from fire targets. The detectors are mounted adjacent to each other normal to the scan axis. To put the two signals in register, the indium channel is delayed a period proportional to the detector spacing.

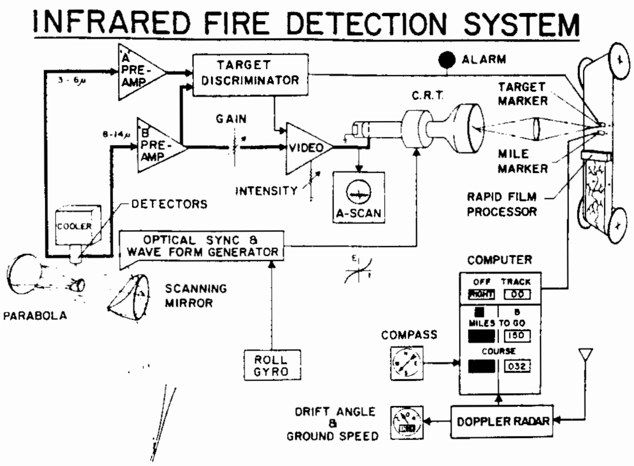

Figure 3.—Schematic of IR two-detector fire detection system.

The 8- to 14-micron channel intensity modulates a high-resolution cathode ray tube (CRT). A scanner-generated, roll-corrected sync pulse triggers a tangent sweep waveform generator. Five-inch panchromatic film is pulled past the CRT at a speed proportional to the aircraft's velocity/height ratio. An onboard Doppler radar and a navigation computer provide a means for controlling the flight path. One-mile pulses from the Doppler are recorded on the edge of the film to facilitate ground reference. The film is processed in near-real time by a hot, wet chemical, two-step processor. The processed film crosses a back-lighted viewing station and can be read within 2 minutes after exposure.

An AGC loop controls the gain of the 8- to 14-micron channel to produce a zero difference between the two channels when averaged over several scan lines. Short pulses from a hot target are not averaged, but are used to trigger the target discrimination module (TDM). The resulting cancellation of background signal markedly enhances the fire target-to-background ratio. Figure 4 shows a comparison of the raw video signals with the difference channel.

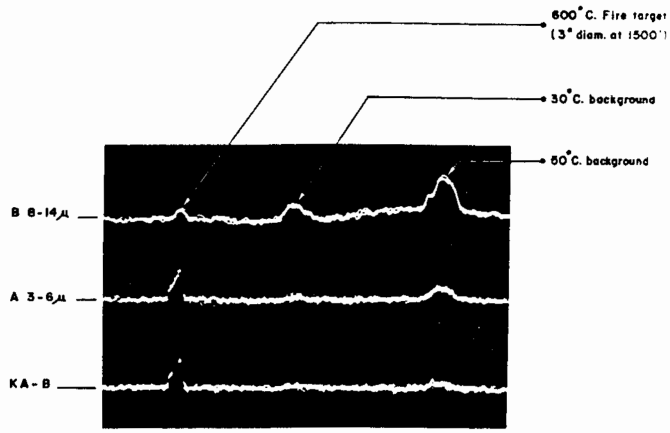

Figure 4.—Oscilloscope traces depicting target enhancement by spectral discrimination.

The difference channel output is pulse-height/pulse-width discriminated. A pulse above a preset threshold and within the pulse-width limits produces a logic pulse that is stored in a digital memory for one scan line. If a logic pulse is produced at the same point in two successive scan lines, an output pulse is generated. A film edge mark and a pulse delayed by several resolution elements is reinserted in the video, cuing the operator. The scan-to-scan comparison eliminates false alarms from random electrical noise.

At present, we are testing the system operationally on an 8,000-square-mile forested area adjacent to Missoula, Montana. During periods of low and moderate fire danger, one flight per day is made. If the temperature is high and the humidity low or if lightning storms occur, coverage is increased to two and three patrols per day.

This test program is run concurrently with the existing visual detection system, which consists of 59 lookouts and 5 light aircraft. While it may be too early to assess the relative efficiency of the two systems, we can compare total annual operational costs.[3]

In 1968, $211,500 was spent for visual fire detection on the 8,000-square-mile study area. Complete coverage of the same area by the infrared detection system can be achieved at a cost of $100,000.

If these figures can be extrapolated and if the airborne infrared fire detection system can replace the existing visual system, then a potential national saving of approximately $4 million could be realized annually.

Imagery is interpreted in flight. Targets detected are sorted into potential wildfires or legitimate fires of no concern, such as campfires or burning refuse, by comparing imagery to forest maps (Fig. 5). High quality IR imagery is essential for these comparisons. The location of potential forest fires is transmitted immediately on a voice radio channel to fire control personnel.

Late delivery of the aircraft and an unexpected number of equipment problems delayed flight tests until July 23. Also, this has been an exceptionally easy fire season; wildfire occurrence in the patrol area has been less than 5 percent of normal. By August 3 we had completed 10 patrols and detected 284 fire targets, of which 278 were campfires and legitimate smokes.

[3] The annual cost of a lookout, including salary, structural maintenance, depreciation, and support services, is about $3,000. The cost for a light aircraft with an observer averages about $35 per hour.

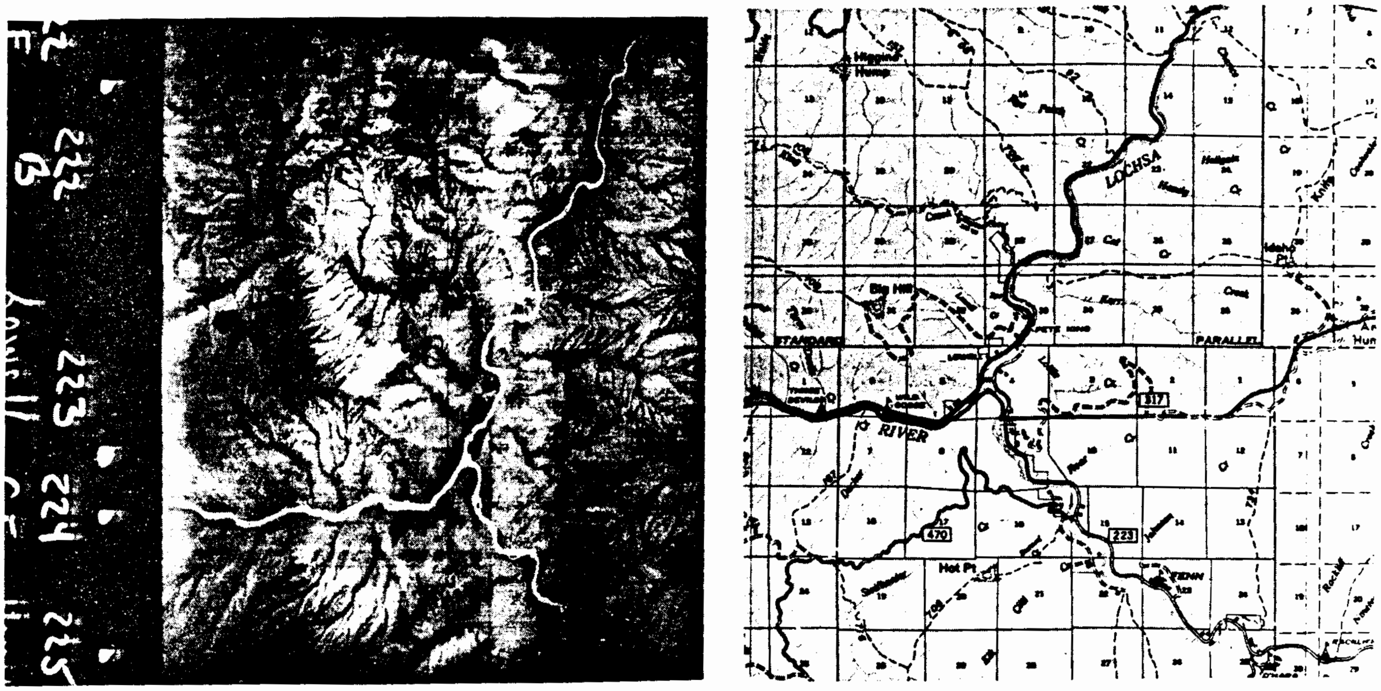

Figure 5.—I, Infrared image covering an area of approximately 800 square miles (the image shows five hot targets and the TDM automatic pulses to alert the operator of the presence of a fire). II, Forest map used in comparing imagery.

FIRE MAPPING

When forest fires are large, the smoke pall often makes it impossible to collect needed intelligence visually. The value of IR line scanners in obtaining fire intelligence through smoke palls has been demonstrated and the techniques are employed on an operational basis (Hirsch et al. 1968).

The system used for fire detection is equally applicable for mapping large fires. The hot areas are near the fire edge, thus the imagery gives a good display of the fire perimeter and any spots that are beyond it. Extreme care was taken in designing the video electronics to prevent d.c. level shift when large-area, hot targets are scanned. To collect fire intelligence, the equipment operator will choose one of three modes of operation. He will use B Channel (8 to 14 microns) to look at a large, vigorously burning fire and A + B Channel (3 to 6 microns + 8 to 14 microns) as the blaze begins to cool. The 8- to 14-micron channel clearly images small details of terrain, making it easy for an interpreter to determine the location of a fire edge with respect to fuel type changes (boundaries between grass and brush and between brush and timber), natural, and man-made barriers. By adding the 3- to 6-micron to the 8- to 14-micron channel, a very effective fire mapping presentation has been obtained. Once a fire is contained and the long, tedious mopup operation is underway, the operator will employ the TDM as a valuable adjunct to either B Channel or A + B Channel.

The recent Newman Ridge Fire, which burned in an area of heavy logging slash, provided us with an excellent opportunity to evaluate our fire mapping capability. The fire was mapped daily from its initiation July 26 to August 3, when mopup was completed. The mapping sequence is shown in figures 6 through 8. The contrast between imagery with and imagery without the TDM dramatically exemplifies the effectiveness of the target discrimination module. Fire suppression crews reported that no open flame was visible July 30, but TDM marks on the imagery made the previous night show smoldering logs and roots. The imagery saved many sweaty, grubby man-hours. However, a lack of TDM marks on imagery can be of equal importance to us. If it were not for the fact that no mark appears in the margin of figure 8, the rock outcropping (arrow) would have been interpreted as a spot fire.

DEFICIENCIES OF THE SYSTEM

The most serious weaknesses of this system for both detection and mapping are in the recording process and in the method for transmitting imagery to the ultimate user. The CRT and the wet film processor are bulky and require continual maintenance. The long hours of patrol are fatiguing and seriously degrade an interpreter's performance. The imagery output is on 5-inch negative film rather than the 9- by 9-inch prints foresters are accustomed to using. We have no satisfactory way to get the imagery from the fire mapping aircraft to remote fire camps where tactical decisions are made.

We badly need a system for telemetering the information from the patrolling or mapping aircraft to centralized fire dispatching headquarters and/or to camps established at the location of large forest fires. We need lightweight, highly reliable, maintenance-free, near-real time recorders that produce hard copy imagery with good gray scale and high resolution.

EQUIPMENT REQUIRED TO OVERCOME DEFICIENCIES

The heat developable, dry silver emulsions being produced by Minnesota Mining and Manufacturing Company (3M) and Eastman Kodak,[4] when coupled with high-resolution, fiber optic CRTs, should solve our recording problems. A prototype recorder, developed by Electro-Mechanical Research under NASA sponsorship, is capable of fulfilling all of the recording requirements shown above. It produces 9-inch hard copy in near-real time with a claimed resolution of 8,000 TV lines and adequate gray scale. The total system weighs 80 pounds and requires 300 watts of input power. We plan to install one of these recorders in our system soon.

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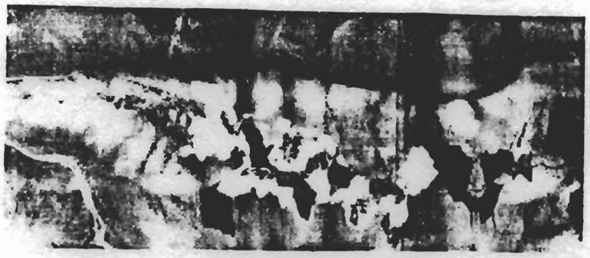
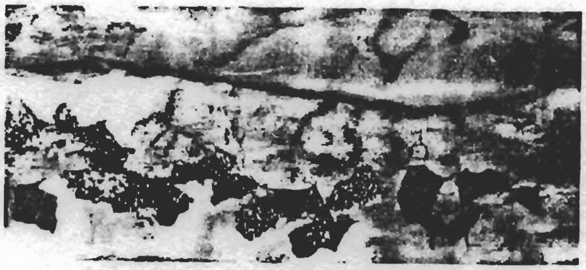
[4] Mention of trade or brand names is solely for identification and does not imply endorsement of products mentioned, nor does it imply nonendorsement of unnamed products.

IR IMAGERY SHOWING MAPPING SEQUENCE OF NEWMAN RIDGE FIRE, LOLO NATIONAL FOREST, U.S.D.A. FOREST SERVICE REGION 1.



JULY 26, 1969 at 0655 hours;
B Channel, TDM off.



JULY 29, 1969 at 2130 hours;
A + B Channel, TDM on.

JULY 29, 1969 at 2120 hours;
A + B Channel, TDM off.

FIGURE 6.

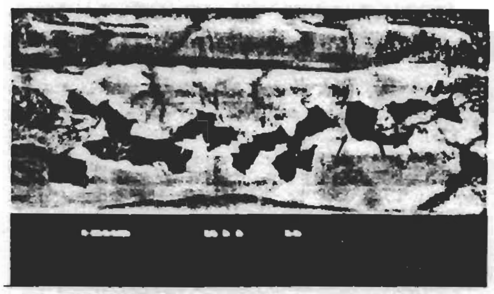
JULY 26, 1969 at 2230 hours;
A + B Channel, TDM on.

JULY 27, 1969 at 2155 hours;
A + B Channel, TDM on.

JULY 29, 1969 at 2130 hours;
A + B Channel, TDM on.

FIGURE 7.

JULY 31, 1969 at 2200 hours;
A + B Channel, TDM on.



AUGUST 2, 1969 at 2155 hours;
A+B Channel, TDM on. Rock outcropping at arrow (no TDM mark).

FIGURE 8.

Unfortunately, we are not that close to solving the telemetering problem. Certainly, telemetering these signals is technically feasible, but can we do it economically? We need to transmit a video signal from an aircraft in which power and weight limitations are stringent. We need to transmit from relatively low altitudes (15,000 feet) for long distances (100 miles) to permanent fire detection bases, and from lower altitudes (3,000 feet) over shorter distances (10 miles) to remote camps where fires are mapped. The ground station for the fire mapping system must be lightweight, easy to transport by pickup truck or helicopter, and relatively inexpensive, since a large number of them would be needed to permit quick delivery to any fire location in the United States.

A telemetering bandwidth of 500 kHz is required if no video processing is done prior to transmission. This bandwidth requires UHF carriers and either directional antennas or a very high-power transmitter, neither is reasonable in this application.

Scan conversion could slow the information rate to that speed actually required for the fire map or the small portion of terrain imagery surrounding a latent fire. This would reduce the video bandwidth to 10 or 20 kHz, permit a lower carrier frequency, and decrease transmission problems. Scan conversion requires a small, lightweight, airborne video processor. We have examined briefly scan converter tubes, magnetic tape, and digital core techniques, but have discarded them all because of resolution, weight, or cost. Current military research and development efforts in scan conversion and image telemetering may provide the needed hardware for our application.

CONCLUSIONS

The value of airborne IR line scanners for supplying needed intelligence on large fires has been demonstrated. Operational tests of IR forest fire detection currently underway should determine the economic feasibility of this technique in fire detection. IR scanners and detectors currently available are suitable for both mapping and detection. Recorders that combine dry silver emulsions and fiber optic cathode ray tubes should provide the needed recording capability. There is an urgent need for scan conversion equipment that would reduce the video bandwidth for economical and practical telemetry.

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