ADVANCED FIRE SENSING AND LOCATING SYSTEMS

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ABSTRACT

There are many ways to label fire sensing and location systems. This paper will address three methods currently in use and how new technologies are being implemented in those. The three methods are: (1) fixed area, with a sensor mounted at a known location, sensing over a selected area; (2) airborne small area, usually with a helicopter or light fixed-wing aircraft; and, (3) airborne large area, from a twin-engine, higher performance aircraft.The systems to be described are considered "advanced" systems because they use technologies or applications of technologies which were not available 10 years ago and in some cases which are still in development. They also will eventually use other advanced systems which are not in general use at this time. The selection of the proper system for the type of situation is important. The relationship to GIS and to fire behavior models will be mentioned.

INTRODUCTION

The use of remote sensing systems, especially thermal infrared (IR), for fire sensing and location, has been in development and use in the USDA Forest Service (FS) for thirty years (Hirsch 1962). The sensing systems could be described as stationary, small area, and large area. Each of these types will be briefly described and application considerations given. Past systems were essentially designed as one integrated system using IR optics, IR detectors, electronic signal processing, and a display product. They were independent of other systems, except for the airborne platform and the human operator and interpreter. Since 1984, IR systems have been combined with other systems and equipment to produce a total integrated system of several subsystems (Warren, Dipert 1988) (Hanks 1986). For example, an advanced system may consist of the basic IR system, navigation receiving system, computer, video display, color TV as an alternate sensor, and RF transmission equipment, on the aircraft. The ground unit, part of the total system may include RF receiving equipment, computer, plotter, video display, and perhaps interactive graphics, coupled with GIS and fire behavior models. Satellite systems have not yet proven practical for the basic fire sensing and location tasks but will be very much needed for support of aircraft location and data/image transmission of the IR information to the ground.

STATIONARY

Stationary fire sensing and location systems have been in use almost forever, if we consider a person on a high outlook post. Later, towers were constructed in selected vantage points to sense and locate fires from visual observation of the fire or resulting smoke. More recently automatic fire sensing and location systems have been proposed and developed. Several are in use in different European countries but for various reasons have had little or no use in the USA. Still the idea is around and would almost certainly have good pay-off in selected areas. The basic method uses a thermal infrared sensing system, sometimes coupled with a visual band system. The IR detects hot spots and the visual detects smoke. The systems are mounted on a tower or pole at a vantage point in a remote location. They scan 360 degrees or selected sector(s) and may include elevation steps on subsequent rotations to extend the coverage. When an abnormal fire or smoke is detected, an alarm is given, visual or aural, at a center. The direction and approximate distance to the fire or smoke is transmitted along with the video. The video display of IR or TV can be selected and viewed by people at a dispatch or other center. Normal fires and smokes from populated areas such as campgrounds, cabins, or other can be programmed into the system memory so that they are ignored. These systems could be placed in existing peopled lookout towers or at other advantageous points. Several can transmit the alarm information and video to the same central location. It would be technically possible now to transmit the information by satellite, and that may be a very reasonable method within a few years when personal communications systems and still-frame or moving image transmission by satellite becomes common.

Applications of stationary systems include fire sensing and location, law enforcement, intrusion detection, smoke management, and pollution monitoring. Fire sensing would be done in selected areas of relatively flat terrain or across the "front side" of mountain ranges where the potential for fire starts exists without other means of early detection. There are many areas in the National Forest Systems where there is a need to protect sites of archaeological interest. Prescribed burn areas may need to manage the smoke and document the results. Industrial activities located on or near public lands may need to be monitored continuously for pollution outputs. Law enforcement may need to monitor certain activities while remaining inconspicuous.

SMALL AREA FIRE SENSING AND LOCATION

A small area will be arbitrarily defined as 1200 acres or less. It should be noted that this could be misleading because much larger areas can be sensed for fire detection given more time. Much larger fires can be located, that is the perimeter and all hot spots of interest plotted or displayed if the entire internal area of the fire is known, or has already burned out. Fire or unburned "islands" inside the main perimeter can also be located or "mapped". Also, often on larger fires, a large portion of the perimeter may be in containment or control, with only the moving front a concern. Thus a small area sensing and location system can often provide complete necessary information on a fire of almost any size.

The small area systems utilize Forward Looking InfraRed (FLIR) or pyroelectic vidicons (PEV) as the thermal sensing unit. The outputs are in standard USA video format and displayed on a black and white or color video monitor. Color video cameras may also be used with the imagery merged or switchselectable for display and recording. Dual monitors and VCR's may also be used. Since 1985, LORAN-C receivers have been used to monitor the location of the aircraft (Dipert, Warren 1988). As a helicopter or small plane flies around a fire perimeter its location is stored every second or two. Spot locations can also be entered, such as hot spots inside or outside the fire perimeter, or any other point of interest. Text or symbols may be used if needed to help describe the points or area. GPS receivers have also been used successfully for fire location (Drake, Luepke 1991). The planning is to go to GPS with differentially corrected data. Notebook size PC's are used to store the navigation receiver location data. These are then connected to a drafting plotter on the ground, scaling points entered and the fire perimeter and hot spots plotted, to scale, on a map or overlay.(Fig. 1) This provides a direct, readily available means for mapping a fire. The use of thermal infrared is essential in order to detect any latent hot areas or spots which could later flare up. Those cannot be detected visibly. The FLIR image is recorded on a standard or SVHS VCR along with the latitude, longitude, time and date, so that a detailed image is available for subsequent review, if needed. Color TV may be selected as an alternate video source, but will not show the thermal conditions like the FLIR video. It may help relate to the area better, though. Sensing areas with FLIR also allows stand-by crews to be released earlier, with confidence that there are no hot spots which may cause later problems.

LARGE AREA FIRE SENSING AND LOCATION

Large areas will be arbitrarily defined as over 1200 acres. For large area fire sensing and location the FS has used airborne thermal IR line scanning systems for about 25 years (Wilson, 1968). These systems have processed the IR information onto film strips developed on the aircraft.(Fig. 2) The aircraft have been twin engine, 4-6 passenger size, and twin turbo-props are presently used. Jet aircraft are now being acquired and expected to go into IR service in a couple of years. Several methods for transmitting the IR images to the ground have been investigated and developed into operating systems, but have seen only limited use because of the cost and complexity of the ground receiving stations. Consequently, the film strips are physically delivered at the nearest landing strip, then driven into the Incident Command Post (ICP). There a trained IR interpreter manually transposes the fire location information onto maps. The IR images on the film strip are at a constantly varying scale because of the mountainous terrain which is usually encountered.

The latest FS airborne IR line scanning system now completing development has been named Firefly. It will use GPS to locate the aircraft, gyro's for monitoring the attitude and bearing, and stored Digital Terrain Elevation Data (DTED) stored on optical disks. With all these sensors and data on-board, computers can determine "instant by instant" where the system is sensing IR band energy on the ground, even on a pitching, rolling, yawing aircraft flying over mountainous terrain.(Fig. 3) When the energy exceeds the selected threshold level at any given instantaneous field of view (FOV) on two successive overlapping scan lines, that ground location will be stored. A relative energy level will also be assigned to that location. The stored data from a flight over a fire will contain all the "hot pixels"' latitude and longitude plus a level assigned representing intensity. As the scanner covers the area, the IR image is displayed on a ɔnitor on the aircraft. The system operator can enter any helpful landmarks or features as annotations to help provide relative position information or other useful data. Freeze frames of the images can also be stored. The lat-lon-intensity data can be transmitted to the ICP after the plane has completed "flying the fire". The plane can then proceed directly to the next fire without needing to land at the nearest landing strip and deliver a film product. At the ICP the data are received and stored in a PC, even a notebook size is sufficient. The computer is then connected to a plotter and the fire pixels are plotted on a map or overlay with their intensity label.

WHY ARE THESE ADVANCED SYSTEMS?

In a recent issue of the HP Journal a figure in an article showed the dramatic increase in software content of one of their product families from 1979 to 1989 (Bear, Rush 1991). In 1979 there was no software at all. In 1983 there was a small amount, in 1986 a noticeable amount and by 1989 it was dominant. A graph of the FS IR systems would show no software in 1979. In 1984 the SW was a significant portion of the Fire Mouse Trap (FMT) system. In 1992 SW will be a significant portion of the Firefly (FF). In less than 10 years we will have gone from no computers to computer dependent systems for our IR capability. Both the FF and FMT will use the GPS which is not yet fully operational. Both use other equipment such as packet radio modems and plotters which have advanced in features and reduced in size, weight and cost so that they can be a part of an airborne or supporting ground system in remote and sometimes hostile environments. The FF also uses DTED stored on optical disks and is still waiting for data and image transmission technology to be available from moving aircraft to the ground via satellite links. So at least based on a 10 year scale, these systems are "advanced" in ways which were not feasible that long ago. There is no claim here that these are on the cutting edge of technology, just that they are taking advantage of technology as it become available, and in some cases waiting impatiently for the technology to become practical or lower in cost. There is no question that interesting new things could be accomplished if military-sized budgets were available.

FUTURE ADVANCEMENTS

Without speculating out as far as 10 years which is always interesting, there are several advances which can be anticipated for fire location and sensing. These will build on the FF and FMT systems capabilities. Specifically for FF, there is a need for real-time differential GPS corrections on board a moving aircraft over remote areas. That would greatly improve the accuracy of the locations calculated by FF. The need for data and image transmission from aircraft, via satellite is also necessary to realize the full time savings advantage of FF.

There is a need to have interactive graphics displays of 3-D maps around the areas of large fires. On these displays the IR images, hot spots, fire perimeters from the FF or FMT should be overlaid to give a vivid 3D view of present fire location and activity. GIS layers would show predicted fire movements, fuels, high value property, and other pertinent features.(Fig. 4) There is a real need to overlay, to the correct scale and in the correct locations, the images and hot spots from the FF along with the fire perimeter and FLIR images from FMT.

Fusion of data and images from various sources, to scale, on a common map base would provide fire staffs with the best overall view of the incident or fire. Expert systems could help select the correct IR system to provide additional intelligence needs at any stage of the fire. For non-fire incidents the FMT with color video could provide locations and scenes of the areas in real or near real time.

CONCLUSION

The FS is moving from traditional stand-alone IR systems to more advanced methods using several integrated sub-systems, each adding to the usefulness or content of the IR data. The use of computers in both airborne and ground systems is here in both the larger airborne systems and the FLIR-based more portable systems. Satellites although still not practical for direct sensing and location of fires, for several reasons are used for locating the aircraft and thus either directly (FMT) or indirectly (FF) for locating the fire. Transmission of IR data and images by satellites will also be done within a few years. Computer display and interactive processing of images and data are likely to become available and used to take best advantages of the various types of IR systems outputs at the ICP's.

REFERENCES

Bear, S.P. and Rush, T.W. 1991, Rigorous Software Engineering: A Method for Preventing Software Defects, *Hewlett-Packard Journal*, Dec., 1991.

Dipert, D. and Warren, J.R. 1988, Mapping Fires with the Fire Mouse Trap, *Fire Management Notes* 1988 Volume 49, Number 2.

Drake, P. and Luepke, D. 1991, GPS for Forest Fire Management and Cleanup, *GPS World*, Sept., 1991.

Hirsch, S.N. 1962, Infrared as a fire control tool, *Western Forestry Fire Research Council Proceedings*, 1962:5-10

Wilson, R.A. 1968, Fire Detection Feasibility Tests and Systems Development, *Fifth Symposium on Remote Sensing of the Environment Proceedings* 1968: 465-477.

FIRE MOUSE TRAP SYSTEM

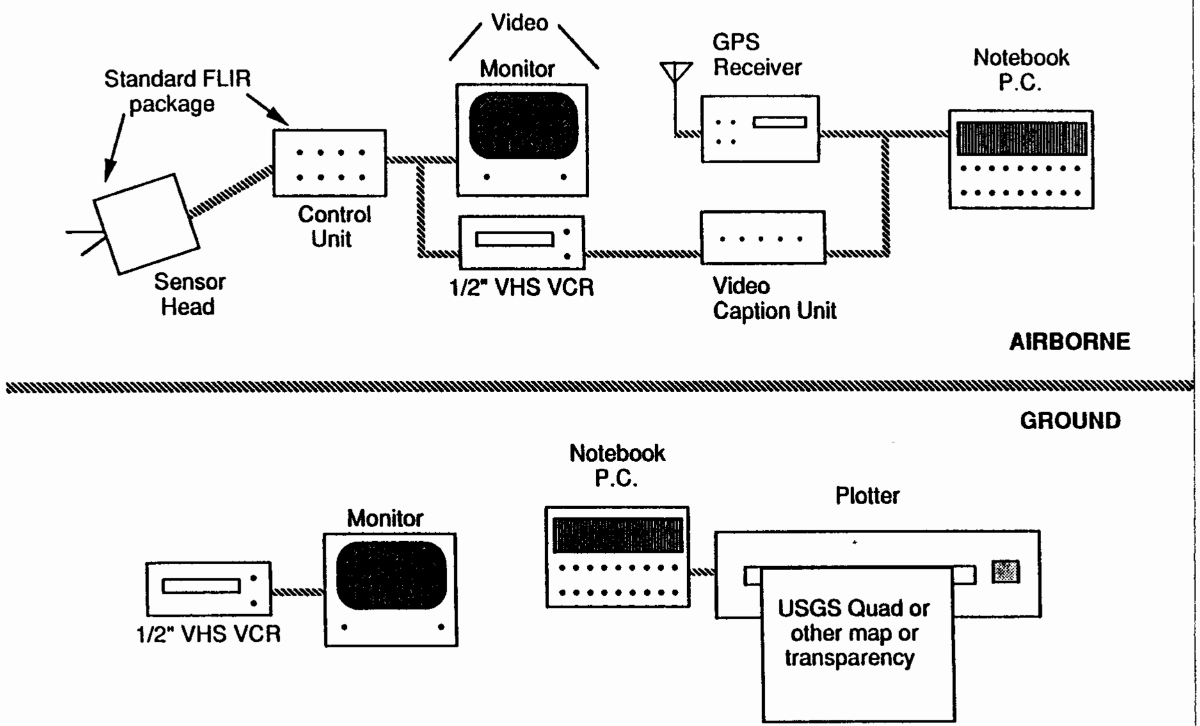

Figure 1

INFRARED FIRE SURVEILLANCE SYSTEM

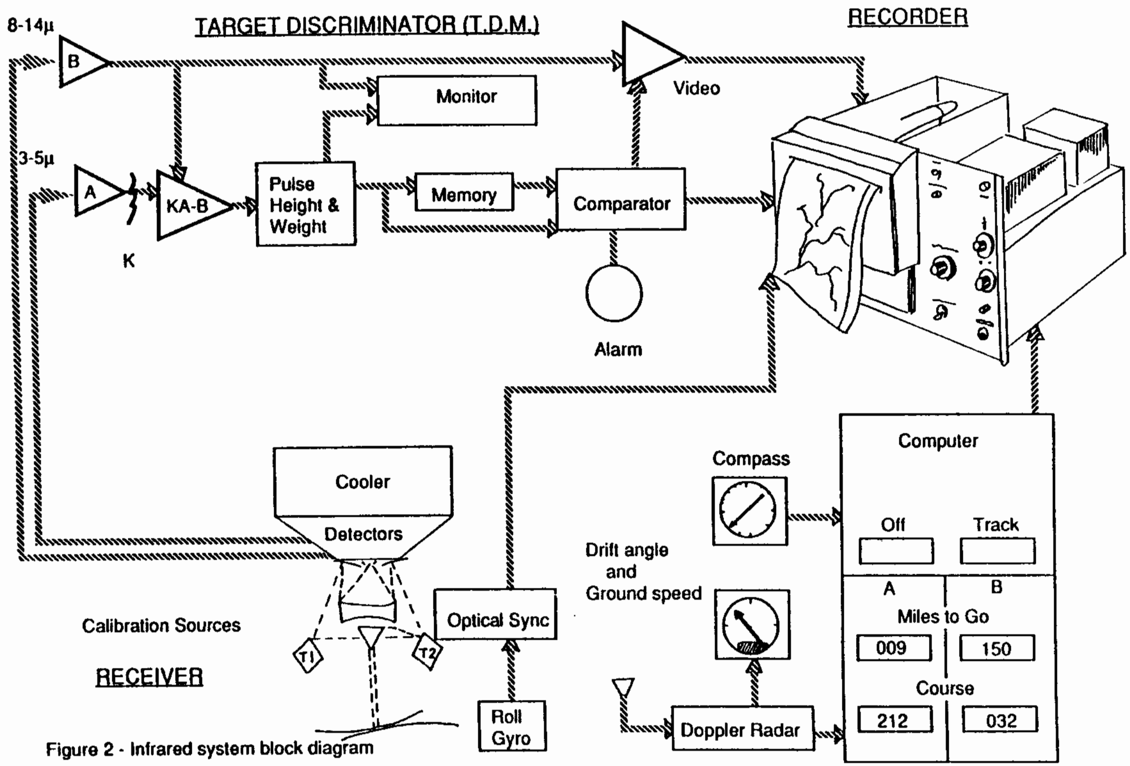

Figure 2 - Infrared system block diagram

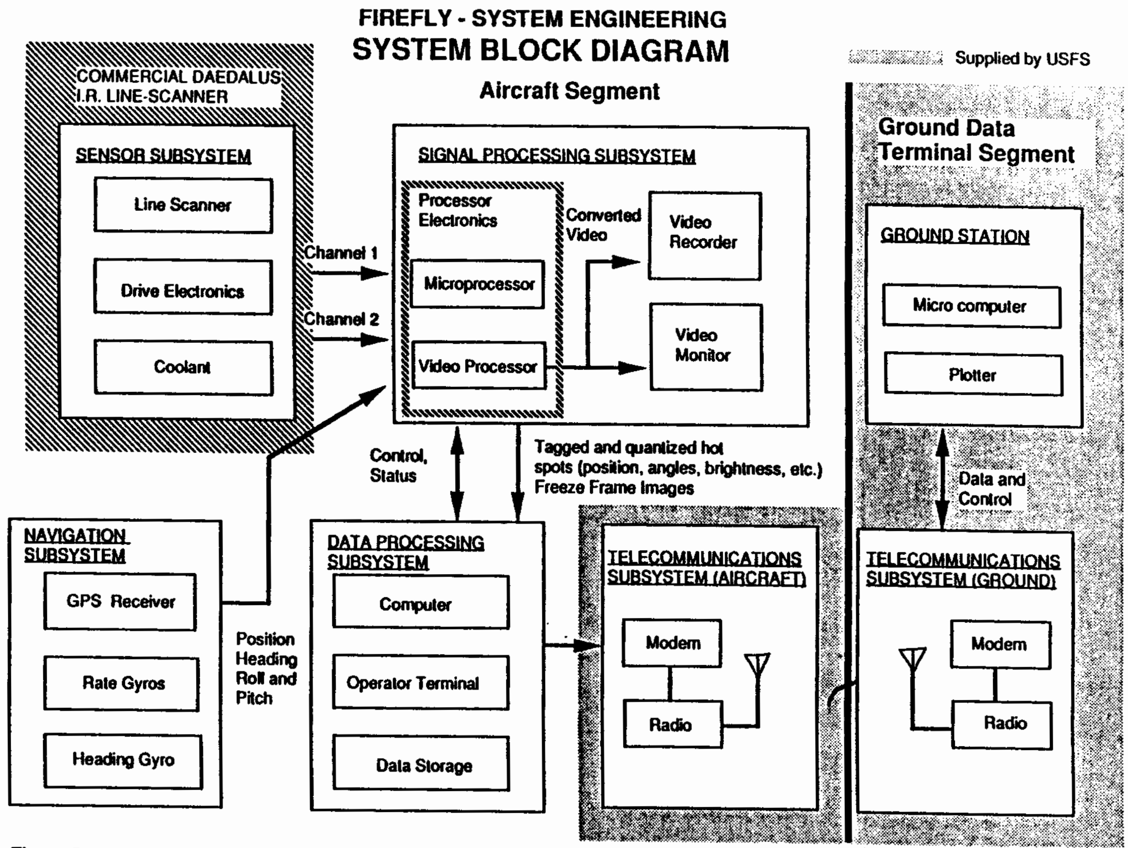
FIREFLY - SYSTEM ENGINEERING
SYSTEM BLOCK DIAGRAM
Aircraft Segment
Supplied by USFS
COMMERCIAL DAEDALUS
I.R. LINE-SCANNER
SENSOR SUBSYSTEM
Line Scanner
Drive Electronics
Coolant
Channel 1
Channel 2
SIGNAL PROCESSING SUBSYSTEM
Processor
Electronics
Microprocessor
Video Processor
Converted
Video
Video
Recorder
Video
Monitor
Control,
Status
Tagged and quantized hot
spots (position, angles, brightness, etc.)
Freeze Frame Images
NAVIGATION
SUBSYSTEM
GPS Receiver
Rate Gyros
Heading Gyro
Position
Heading
Roll and
Pitch
DATA PROCESSING
SUBSYSTEM
Computer
Operator Terminal
Data Storage
TELECOMMUNICATIONS
SUBSYSTEM (AIRCRAFT)
Modem
Radio
Ground Data
Terminal Segment
GROUND STATION
Micro computer
Plotter
Data and
Control
TELECOMMUNICATIONS
SUBSYSTEM (GROUND)
Modem
Radio

Figure 3

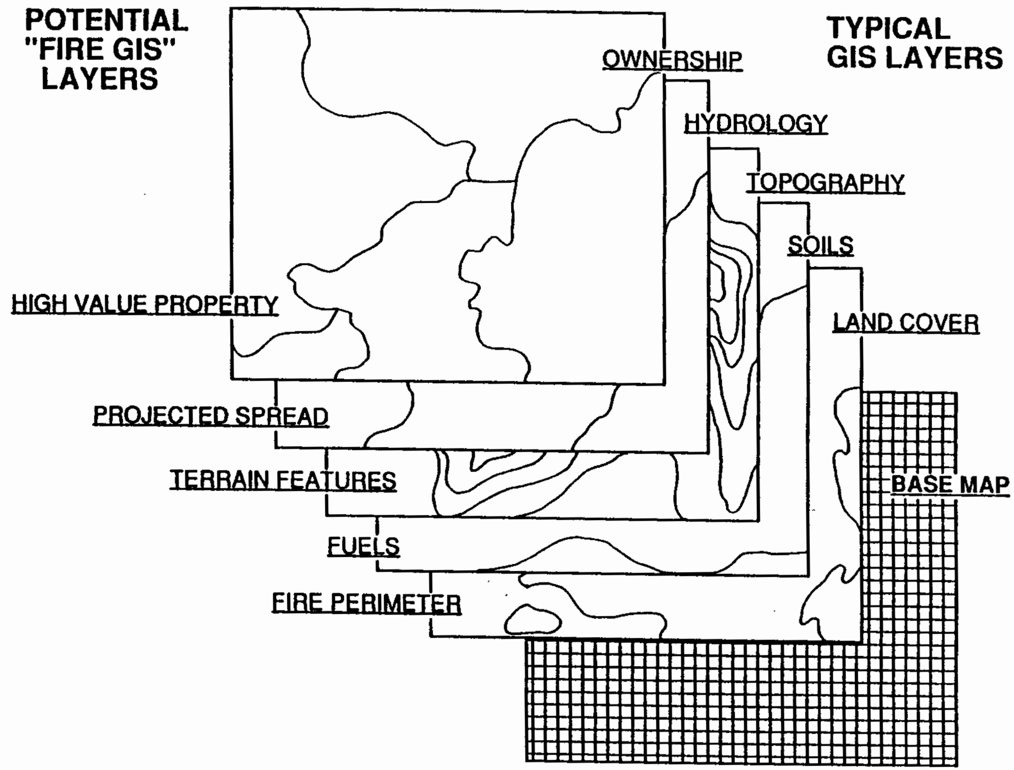
POTENTIAL
"FIRE GIS"
LAYERS
TYPICAL
GIS LAYERS
OWNERSHIP
HYDROLOGY
TOPOGRAPHY
SOILS
LAND COVER
BASE MAP
HIGH VALUE PROPERTY
PROJECTED SPREAD
TERRAIN FEATURES
FUELS
FIRE PERIMETER

Figure 4