Forest Fire Advanced System Technology (FFAST): A Conceptual Design for Detection and Mapping[1]

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Abstract: The Forest Fire Advanced System Technology (FFAST) project is developing a data system to provide near-real-time forest fire information to fire management at the fire Incident Command Post (ICP). The completed conceptual design defined an integrated forest fire detection and mapping system that is based upon technology available in the 1990's. System component technologies identified for an end-to-end system include airborne mounted thermal infrared (IR) linear array detectors, automatic onboard data georeferencing and signal processing, satellite communications links, and advanced data integration and display. The conceptual design detailed the preferred system configuration that warrants continued refinement and development for operational use in the 1990's. The FFAST design will be the baseline for the next generation of forest fire detection and mapping systems after the year 2000.

Thermal IR sensing for forest fire detection and mapping has been under development and use by the USDA Forest Service since the FIRESCAN Research Project began in 1962 (Hirsch 1968).

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Project FIRESCAN was a study to examine the use of airborne, IR line scanners for detecting latent forest fires and for mapping the perimeter of large fires. The original Forest Service airborne. IR, line-scanning systems were based upon research conducted during the FIRESCAN Project. The Forest Service has used fire mapping systems operationally since 1964 (Warren and Wilson 1981). The initial airborne systems were stand-alone IR systems designed to produce hard-copy images, onboard the aircraft, of thermal characteristics of the terrain and fire. Timely delivery of fire imagery to a fire camp was a problem as the imagery was delivered either via drop tube, conditions permitting, or hand delivered via ground transportation from the nearest airport.

The original scanner units became obsolete due to improvements in technology and the increasing difficulty in maintaining the units for operational readiness. Replacement parts for the scanner units were difficult to find and in some cases had to be custom built.

The Fire Logistics Airborne Mapping Equipment (FLAME) project, a joint effort between the Forest Service and the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL), was charged with designing, developing, and implementing a modern, airborne, IR detection system with improved performance and flexibility over the original systems (Enmark 1984). As a result of the FLAME project, the Forest Service's Texas Instruments RS-7 scanner was replaced with a hybrid system providing increased spatial resolution (instantaneous field of view of 1 milliradian), improved response time and data capture, and real-time video display and storage.

The Forest Service airborne sensor systems in use today are the only ones in the world designed specifically for fire detection and mapping. The systems are rotating-mirror, thermal IR line scanners that use dual-element detectors in the 3 to 5 and 8 to 12 micrometer bands. The field of view (cross track of 120 degrees) is rapidly swept across the flight line in a direction perpendicular to the aircraft's axis. The sensor systems are relatively large and heavy, require large amounts of power, and need liquid nitrogen for cooling. The physical delivery of fire data to the fire camp ICP normally requires 1 to 4 hours, followed by 1 to 2 hours of scaling and interpretation.

The inability to deliver timely IR fire information to fire management personnel has continued to be a serious problem. IR data collection, image data transmission, processing, storage, and display systems using the latest technological advances must be identified and evaluated to meet the critical challenges facing the Forest Service. A joint effort to examine this problem was initiated between JPL and the Forest Service in 1983.

OBJECTIVES

The objectives of the conceptual design study were to examine in detail user requirements for tactical information on forest fire activity, document functional requirements for a completed system, examine technology that will be available for application to the project objectives, and prepare a preferred system configuration. The results of the conceptual design will be applied to forest fire mapping and detection to be used by the Forest Service and cooperating agencies in the 1990's. To accomplish the objectives, uncertainties in emerging and advanced technologies related to the conceptual design were identified. Operational capabilities and characteristics as well as functional requirements were determined.

APPROACH

Analysis of component and subsystem technologies and function were performed, including value analysis,[3] tradeoff evaluation process[4] studies, and projection of technology availability. Areas of risk were identified and alternative approaches defined. This approach was followed to maintain the appropriate technology level for the system and to ensure that the most economic means of design and implementation are pursued.

There are five basic considerations behind the design philosophy of the FFAST system. The first consideration is that the new system will have improved timeliness over the current system. The new system will produce the end product within 30 minutes of actual data collection. The second consideration is the improved accuracy the system will have over the existing system. The third consideration is the modularity of the design to facilitate service, reliability, maintainability, possible upgrading, and long life. The fourth consideration is the ease with which the system can be used. Extensive operator training should not be required. A user manual should be necessary only during initial training and to remind the operator of the full capabilities of the system after a period of no usage. The fifth consideration is the use of commercially available components, when possible. Off-the-shelf components will decrease system development costs.

FUNCTIONAL REQUIREMENTS

To support the conceptual system design effort, a set of functional requirements for the FFAST system was developed (Dutzi 1984). Functional requirements were based upon the identified user needs compiled from meetings with Forest Service Regional Fire and Aviation Management Directors and their staffs, and technical judgement. The functional requirements identify the functions necessary to satisfy user needs for a fire detection and mapping system with improvements over the system used currently. The FFAST functional requirements fall into two categories:

1. Basic requirements:
    a. Accurate data acquisition.
    b. Timely georeferencing of fire data.

[3]Methodology is from the USDA Forest Service Value Engineering Workshop. Washington, D.C., November 28 to December 1, 1983.

[4]Methodology is from the USDA Forest Service Tradeoff Evaluation Process Workshop, Boise, ID. October 10, 1984.

c. Timely delivery of thermal IR image data.
d. Improved voice and data communications.
e. Improved image processing capability.
f. Improved data reduction and display.
g. Compatibility with other systems.
h. Conventional map output products.
i. Reliable, rugged, and easily maintainable.

2. Desired attributes:
   a. Integration of distributed data bases.
   b. Modeling capability.
   c. Adaptable to other forest management areas.
   d. Easily integrated into Forest Service procedures.

The functional requirements provide a framework for the conceptual design effort. The baseline design description will use the functional requirements as a foundation from which to develop components that will fulfill the objectives of the FFAST project.

BASELINE DESIGN

The conceptual design of the FFAST system focused upon technology that will be available and sufficiently mature by the 1990's to aid users in fire detection and mapping. The baseline design supports the development of system components that will meet the functional requirements objectives.

Collection of Fire Data

Thermal IR sensing of forest fire perimeters and related hot spots is performed in the two prominent atmospheric transmission windows, 3 to 5 and 8 to 12 micron bands. Instruments operating in these two bands are able to detect fire and terrain features through smoke clouds.

Two thermal IR sensing methods can be useful in fulfilling the functional requirements for the collection of fire data. The current method in use is infrared line scanners that have single- or dual-element detectors. Line scanners work when the field of view is rapidly swept across the flight line in a direction perpendicular to the aircraft's axis. The system scanning mirror must move fast and must be rigidly supported to produce good images. Thus, line scanners tend to be massive and built on a custom-design basis. The second method is the use of linear array detectors configured to produce an image from the ground swath as the system is flown over the site of fire data collection. The linear array is oriented perpendicularly to the aircraft axis and each detector traces a separate line on the ground. The linear array detector design is commonly referred to as a pushbroom scanner because the detectors are being pushed across a scene as opposed to being swept from side to side as in the design of the line scanner.

Linear array, IR detector systems are currently available on a custom-design basis built to meet user requirements. The materials used are mercury-cadmium-telluride for the 3 to 5 micron range currently available, and either the same materials or gallium-arsenide, which are projected to be available by 1990, for the 8 to 12 micron range. Element dimensions vary with up to 128-element arrays presently being built. Larger arrays are projected for future production. The linear array lightweight and small size, about 50 kilograms (approximately 100 pounds) when combined with a storage device and microcomputer processor, make such system components ideal for use in aircraft platforms smaller than those presently used by the Forest Service for IR missions.

Fire Data Processing

Forest fire detection and mapping involves the comparison and contrasting of variables associated with fire behavior. The most important need is the ability to locate fire targets produced from the IR data collection system with respect to known geographic positions on the ground. Fire targets can be positioned if the IR image data is georeferenced to a standard cartographic base (map).

To georeference fire data, it is necessary first to know the position of the sensor platform (aircraft) and then the location of the scene imaged by the sensor system; this image data is then correlated with the cartographic base. The standard georeference correlation procedure identifies common points between the IR image data and the map, then uses the common points to overlay the image data on the map.

A number of technology items were identified in the design technology assessment as possible candidates for determining the location of the sensor platform for georeferencing. Alternatives included LORAN-C, Geostar, Inertial Navigation System, OMEGA, TRANSIT, and the NAVSTAR Global Positioning System (GPS).

The GPS is being developed to provide highly precise position, velocity, and time information to users, 24 hours a day, worldwide. The navigation position accuracy will exceed the requirements of FFAST. GPS hardware and software are available commercially.

Communications

The communication component is the single weakest link in the existing system. The inability to deliver the data reliably in a short period of time (less than 30 minutes) has hampered incorporation of fire data in the daily fire suppression plan. Land lines in remote locations are not readily available and VHF/UHF communications are limited to line of sight or repeater networks. The most promising method of communication appears to be via satellite link.

Remote mobile land and aeronautical communications via satellite will provide service comparable to current urban cellular telephone systems, but on a nationwide basis. Satellite communications are based on the positioning of a satellite in an equatorial, geostationary orbit at an altitude of 22,300 miles. Communication stations transmit and receive voice grade data via the satellite. Two or more stations work in a duplex mode (simultaneous transmission and reception) using the satellite as a relay.

Fire Data Display

The functional requirements dictate that the final output of the FFAST system be accepted and used by the fire control management at the ICP. Image data processing techniques and equipment are available to extract, enhance, reduce, and display fire data in a number of formats.

Historically, fire perimeter information is plotted on a standard map base, usually a standard United States Geological Survey (USGS) 7-1/2 minute quad map. Fire data plotted on a map base is the display product users require. The fire data that should be included in the end product will be the fire perimeter, fire hot spot, and fire intensity. The fire data, transmitted from the airborne platform via satellite voice/data grade links to the ground station, will be automatically scaled and plotted accurately. Ground station equipment, a small ruggedized personal computer and a pen plotter, have been demonstrated operationally by the Forest Service.

TECHNOLOGY ASSESSMENT FOR BASELINE DESIGN

The FFAST system baseline description prompted the assessment of technologies that could be considered potential system components. The technology assessment, detailed in Nichols and Warren (1986), was an analysis made to address the following items:

1. Sensor systems.
2. Global positioning technologies.
3. Georeferencing techniques.
4. Satellite communications.
5. Data bases and Data Base Management Systems (DBMS).
6. Data storage devices.
7. Data display devices.

The technology assessment of each of these items is in terms of its application to the FFAST system, and its projected availability as a result of continued technical evolution. Accordingly, the technology assessment implies that the FFAST system is modularized, and that the new technology items can be integrated into the system configuration as they become mature and commercially available. Because of likely availability, the emphasis of the technology assessment is on nonclassified technology. Only those commercially available items that have been technically proven will be considered for possible final system integration.

ALTERNATIVE FFAST SYSTEM CONFIGURATIONS

Alternative FFAST system configurations have been developed with regard for future Forest Service information needs. The alternatives are intended as baseline configurations. The preferred system configuration was formulated as a design on which a subsequent detailed design may be built. The alternative configurations and their associated technologies, detailed in Nichols and Warren (1986), aid in the refining of the total system design. An alternative FFAST system configuration matrix summarizing the alternatives is presented in table 1. The current Forest Service IR system is used to allow a point of comparison.

The candidate FFAST system configuration alternatives were evaluated for factors considered to be of paramount importance when comparing potential system configurations. The FFAST alternative configurations, with a delivery of fire data to the fire ICP in less than 30 minutes, have at least a 3-hour advantage over the present IR system. The FFAST system configuration option A alternative has the line scanner disadvantage of projected high maintenance, difficulty in calibration, large size, and weight. The option C alternative uses a single-band linear array, which is a technical uncertainty. The single-band linear array may not provide a fire detection capability that will meet the system functional requirements. The option D alternative would utilize a central ground facility to process the uncorrected IR data of fire perimeter and intensity. Option D would retransmit the fire data to the ICP. The transmission and retransmission of the data in option D and the use of the processing at a central ground facility would consume extra time, causing potential system inefficiencies.

Table 1--Alternative FFAST system configuration matrix

Component	FFAST alternatives				Current system
	A	B	C	D	
Collect data					
Line Scanner	X				X
Linear Array 1 band			X		
Linear Array 2 bands		X		X	
Data processing					
Advanced georefer-encing	X	X	X	X	
Advanced registra-tion	X	X	X	X	
Automated on-board aircraft	X	X	X		
Registration and rectification at ground facility				X	X
Communication					
Satellite	X	X	X	X	
Data display					
Advanced display at ICP	X	X	X	X	
Platform-size class					
King air	X				X
Merlin	X				X
Baron		X	X	X	

Option B is the best FFAST system alternative configuration based on the results of the evaluation processes. The dual-band linear array component used in option B is the most promising alternative as verified by the fire data collection analysis procedure. Onboard data georeferencing is an important factor in producing the end product in a timely manner. Satellite communications allow option B to transmit data in near-real time without the concern for line-of-sight data transmission. The compact size of the option B system will allow the platform to be a smaller aircraft than presently used. The option B configuration has the least amount of technical uncertainty, the advantage of onboard data processing, and small size, while still meeting the functional requirements of an advanced forest fire detection and mapping system.

PREFERRED SYSTEM CONFIGURATION DESCRIPTION

The FFAST preferred system configuration (option B alternative) is shown in figure 1. The thermal IR linear array will use two 1024-element linear arrays, one in the 3 to 5 micron band and the other in the 8 to 12 micron band. Dichroic beam-splitter optics will separate the energy input in the two bands and route them to the appropriate arrays. The

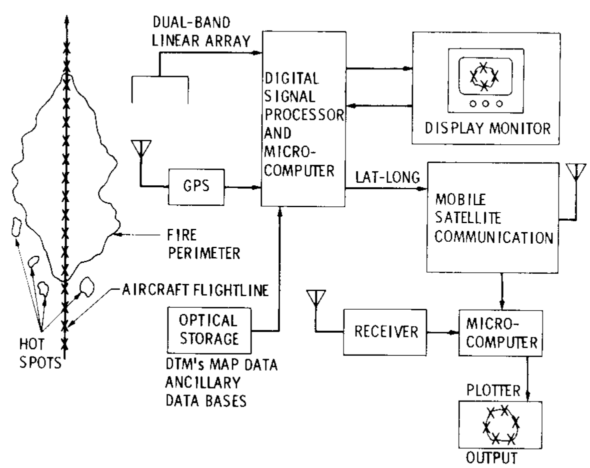

Figure 1--Preferred system configuration.

dual-band array-will retain the same detection capability achieved in the Forest Service's existing airborne IR line scanning systems yet it will be smaller, lighter, and more easily transportable to smaller aircraft. The output of each corresponding detector element in the two arrays will be synchronized, pixel by pixel. Hot spots must pass a predetermined signal criteria to be recognized as legitimate targets. The outputs of the two bands are subtracted in a scaled manner (kA-B), which leaves the target (hot-spot) signals outstanding. The signals are stored in a one-line buffer. The ground area is deliberately over-scanned so that every pixel area is viewed at least twice. The target must show up at the same pixel location in the next scanned line to be accepted as a real target. This eliminates random noise spikes from passing the target selection criteria and thus greatly reduces the false alarm rate. The 8 to 12 micron band is used for target verification and displaying terrain features to coordinate with maps, orthophotos, and other data stored onboard the aircraft. The 3 to 5 micron band will provide target information.

The thermal IR image data is correlated to ancillary data onboard the aircraft. Stored image features, such as roads, streams, ridges, and other known physical characteristics may be highlighted by the system. The IR image will be digitized and stored for display along with the previously stored images. When the images are overlayed on the video/graphics display monitor, identifiable features will be matched to remove any distortions in the IR image and to correlate with the map data.

The GPS receiver will provide precise information on the position of the airborne platform. The positional data will be stored onboard for display and computation. Maps and images stored on optical disks can be displayed on the graphics display monitor with the aircraft track superimposed. The location of the aircraft, stored terrain elevation features, and the IR image data can be positioned simultaneously and scaled on the display unit. When all pertinent characteristics are matched, fire perimeter and associated hot-spot fire target data will be highlighted to register automatically and store latitude and longitude points.

Upon completion of fire perimeter and other point storage, the data will be transmitted via a geosynchronous communications satellite link (voice grade, low data rate) and received at various locations including the ICP. The fire data will be stored in a field-durable, portable computer, and subsequently plotted on a USGS topographic map for use by the fire management team.

CONCLUSIONS AND FUTURE DEVELOPMENTS

The preferred system configuration will meet or exceed the user's functional requirements for an advanced forest fire detection and mapping system. The entire system will be transportable from one aircraft to another, thus precluding the need for a dedicated, large (twin-turboprop-size) aircraft. The modular design of the preferred system provides flexibility by allowing the incorporation of both present and developing technologies. The preferred system will make it possible to acquire and integrate the requisite information into a high-resolution, user-friendly system which will perform fire detection and mapping on a near-real-time basis. The system will also be adaptable to nonfire, multiple-user reconnaissance missions by incorporating the use of sensors other than those in the 3 to 5 and 8 to 12 micron bands.

The FFAST conceptual design was based upon sound engineering design practices utilizing technology either available today or reaching maturity in the near future. The FFAST operational system will be nearing the end of its design life in the year 2000.

The next generation fire and mapping system will be based upon technological advances that are foreseeable today and may occur in the next 13 years. Technological advances will be made in the areas of sensor development, optics, observational systems, and precise locational capabilities as direct spinoffs from development work for the U.S. Government's Strategic Defense Initiative and ongoing NASA space exploration activities. Remotely piloted vehicles may develop to the point of being able to carry extremely compact, ultrahigh-resolution sensor systems capable of sensing, processing, and transmitting tremendous amounts of data. Fire data could be coupled with multiple databases (such as topographic map. fuel moisture, rates of spread, fire behavior, resource values, economic impact models, fire effects models, weather data) integrated and displayed on a pocket-size video monitor for fire personnel in the field. High-resolution earth-observing geosynchronous satellite systems using sensors capable of seeing through clouds and smoke may be able to monitor constantly both high-fire-danger areas and ongoing wildland fires. Instanteous [sic] voice, video, data and data communications could be achieved through satellite links. Interactive computer-based systems will synthesize real-time fire information to assist fire managers in making technically complex decisions.

Rapidly advancing technologies promise solutions to fire management information needs and the development of the next generation fire detection and mapping system.

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