DESIGNING AND IMPLEMENTING A NEAR REAL-TIME WILDLAND FIRE INFORMATION SYSTEM

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INTRODUCTION

Management of wildland fires requires timely and accurate information on fire location and behavior. The "Firefly " project is building an infrared (IR) remote sensing system that will provide near real-time wildland fire information for fire management and suppression. Firefly is under development for the Forest Service, United States Department Of Agriculture at the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL). Recent technological advances in several technical areas now allow the design of an end-to-end infrared linescanner system to map and detect wildland fires. The system components will include an airborne infrared linescanner, automatic onboard signal and data processing, a telecommunications link, and integration into a ground data terminal. The system will enable fire suppression and management personnel to acquire detailed information on the fire perimeter, hot spot (small fire) and thermal intensity necessary for fire management, logistics, and suppression.

Firefly is an outgrowth of past collaborative efforts by JPL and the Forest Service on the Fire Logistics Airborne Mapping Equipment (FLAME) Task (Enmark, 1984), and the Forest Fire Advanced System Technology (FFAST) Feasibility Study (McLeod et al., 1983). The objective of the FLAME task was to upgrade the electronics within the existing early 1960s vintage Forest Service IR linescanner systems. The FLAME task provided improvements to IR line-scanning capability, however, FLAME required manual image interpretation in order to process the IR output. The ability to deliver timely, consistent, and quantifiably accurate IR fire information to fire management personnel continued to be a serious problem even after the delivery of the FLAME system. The FFAST feasibility study concluded that an advanced system could be developed to produce an end-to-end thermal IR fire detection and mapping information system. The Firefly definition phase was the result of the FFAST Feasibility Study.

The Firefly definition phase detailed functional requirements, defined system performance specifications and refined a design approach that could be utilized to build a system to meet the Forest Service fire detection and mapping mission needs (Nichols, 1988).

The Forest Service plans to take advantage of the advanced technology, defined by the Firefly definition phase, in the development and implementation of the Firefly system. Firefly will build upon research, development, and operational use conducted over the last 25 years, and engineering studies and analyses conducted over the last 5 years (Warren and Wilson, 1981; Nichols and Warren, 1987).

DESIGN APPROACH

The Firefly System implementation design approach is to develop a modular system to minimize obsolescence and make use of newly developed equipment based upon existing and maturing technology available in the early 1990s. The fundamental requirements for a "user-friendly" system with reliability and maintainability considerations is foremost in the system design approach. The output products will be produced in a near real-time environment defined as delivery to the fire incident manager within thirty minutes after the data collection. The modular design of Firefly will allow the incorporation of additional spectral coverage through integration of sensor capabilities to facilitate non-fire use of the system such as mapping of vegetation stress due to disease or pest infestation.

SYSTEM DESIGN CONCEPT

The Firefly System will be a remote sensing system designed to identify and locate wildland fire perimeters and related hot spots using a special purpose IR sensor. The Firefly System uses information on the aircraft parameters, flight altitude, and sensor field of view to plot the location of the IR data onto a gèographic data base.

The Firefly operational system consists of an aircraft unit and a ground terminal. A typical mission scenario is depicted in Figure 1. The aircraft takes off and flies over the fire area as directed by the fire incident manager. The flight path is designed to enable the on-board sensor to cover the entire fire perimeter area. The aircraft unit images the ground scene, detects fire spots, computes fire perimeter and hot spot locations, correlates fire data to geographic coordinates, and transmits these data to a ground terminal. The aircraft unit operation is controlled by the Firefly airborne unit operator. The operator enables the system when over the fire area, monitors system performance, and relays flight information to the pilot to optimize the flight path. The operator also has the capability to append messages to the data based upon observations of the raw infrared imagery data. At the completion of the data gathering portion of the flight, the aircraft flies to within line of sight of the ground terminal (located at the fire camp) to allow the aircraft and ground terminal computers to transfer the results of the mission via a telemetry data link.

The ground terminal is the primary interface to the system user. The ground terminal receives the fire perimeter and hot spot data from the aircraft, processes the data to an accurate determination of the fire location, then plots these results in a specified geographic scale onto a map or other media.

GEOREFERENCING CONCEPT

Georeferencing is the procedure for determining the fire or hot spot locations relative to a geographic base for plotting the Firefly System output onto a map base. Georeferencing is accomplished by detecting and then graphically locating the fire spots. Separate outputs from a dual color infrared linescanner generate imagery which is processed to detect picture elements (pixels) which pass the fire detection criteria. This processing combines both images and quantizes each resultant pixel for comparison to known thresholds. A Global Positioning System (GPS) receiver is used to determine aircraft position, and gyroscopes are used to determine aircraft attitude and

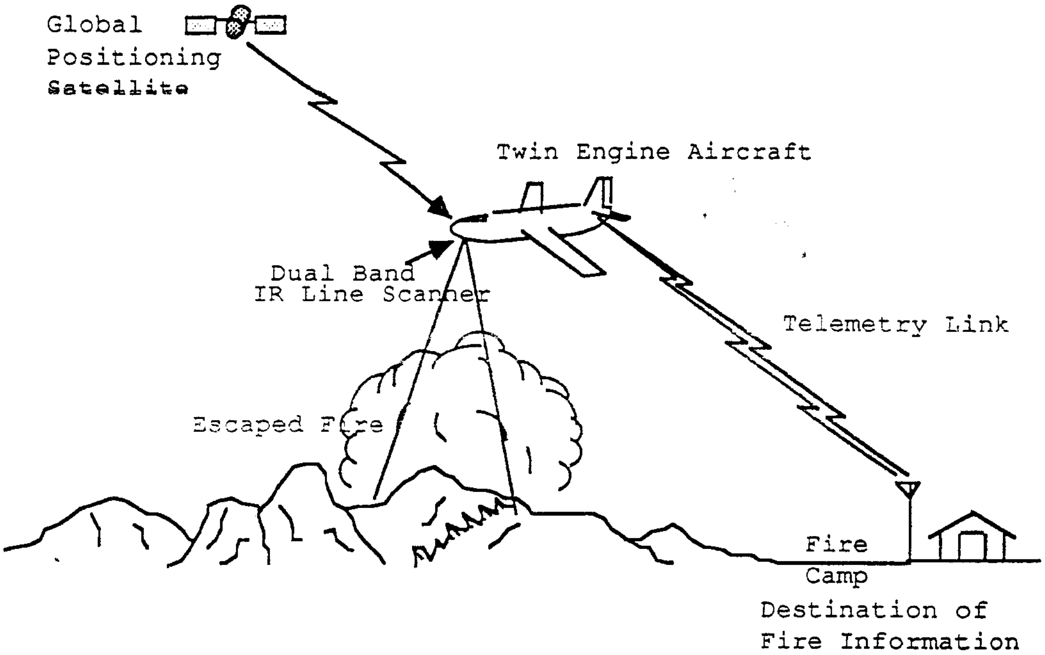

Figure 1   Firefly System Scenario

heading. The aircraft position, attitude, and heading information allows the absolute determination of the fire location along a three dimensional line of sight from the airborne sensor. The information is combined with the range (or distance) the pixel is from the aircraft, which allows the determination of the absolute position of each pixel.

The Firefly georeferencing method for determining the line of sight range of a hot spot from the aircraft uses an existing government data base. The terrain data base (stored on the airborne computer) divides the continental United States in 100 meter squares, each with an average terrain altitude. The on-board processor computes the range from the knowledge of aircraft altitude, the terrain altitude and the sensor look angle.

The fundamental accuracy of the Firefly georeferencing technique depends on the capability to accurately measure aircraft position, heading and attitude. Uncertainties in measuring these parameters will directly correspond to position uncertainties which depend on aircraft altitude and sensor field of view. An uncertainty in the aircraft position (typically 25 to 100 meters for GPS) corresponds directly to an uncertainty in the plot location. Similarly, an uncertainty in the platform attitude and heading (typically 0.1° to 2.0° depending on gyro accuracy) corresponds directly to an uncertainty in the vector angle from the aircraft to the fire.

SYSTEM DESIGN DESCRIPTION

A high level block diagram indicating the relationship between major system components in each of the two segments is shown in Figure 2. The aircraft unit consists of five subsystems, which are: 1) Sensor Subsystem for remotely sensing and imaging the fire areas on the ground, 2) Navigation Subsystem for aircraft location, attitude and heading information, 3) Signal Processing Subsystem for combining the two sensor bands, quantizing fire spots, and integrating navigation data, 4) Data Processing Subsystem for computing the fire location, and 5) Tele-communications Subsystem for transmitting the data to the Ground Terminal. The Ground Terminal consists of the tele-communications component for receiving the aircraft sensor fire data, and the data output component for processing and displaying the fire location data.

Sensor Subsystem

The Sensor Subsystem receives infrared radiation from the fire and converts this radiation into electrical signals for subsequent processing in the Signal Processing Subsystem.

The Sensor Subsystem consists of a special purpose IR linescanner to detect and locate fire and flame hot spots on the ground. Infrared scene emittance is gathered in two IR spectral regions to provide false alarm

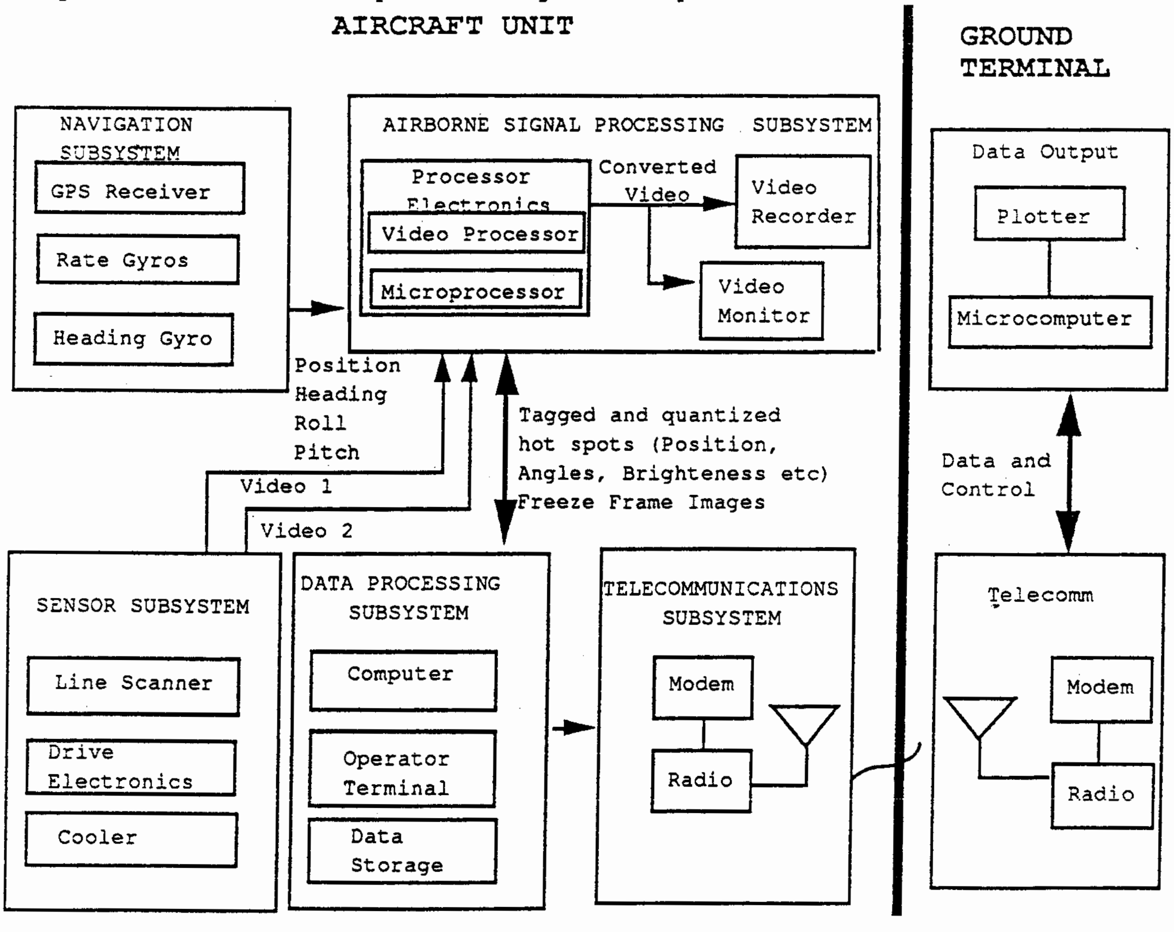

Figure 2. Firefly System Block Diagram

rejection with optimum sensitivity detection. The requirements for bi-spectral imaging, large field of view (FOV), and high spatial resolution make an IR linescanner the sensor of choice. The Firefly sensor requirements are listed in Table 1.

Table 1. IR Sensor Requirements

Field of View	>80 degrees cross track
Detector IFOV	<= 2.5 mrad
Spectral Bands	3-4.8 μm (Channel A)
	8.5-12.5 μm (Channel B)
Sensitivity	<=0.2° K (Both Bands)
Maximum V/H	>=.21 radians/second

Functionally, the IR Sensor Subsystem must address the two primary Firefly tasks of mapping established fires, and detection of point fires ("hot spots"). Both tasks imply requirements which must be met by the sensor. Mapping large fires requires large field of view (at least 80 degrees cross track) and high sensitivity in the long wave IR (LWIR) channel for terrain imaging. Hot spot detection requires bi-spectral imaging for false alarm rejection, wide FOV to maximize the area searched, and high sensitivity in both spectral channels.

Infrared linescanner performance was assessed using the LOWTRAN 6 atmospheric model (U.S. Air Force, 1983). The system spectral bandpasses were calculated to provide uniform degradation to both bands with increasing atmospheric water vapor content. The bi-spectral fire detection algorithms rely on a ratio of the two spectral bands. The analysis suggests that the bands listed in Table 1 will provide very uniform transmission loss, without narrowing the bands too much and therefore reducing sensitivity.

The required sensitivity was calculated with a model developed for the Firefly project at JPL. Due to the very small size of a hot spot, detection requires a relatively small IFOV combined with sensitivity. The sensor must detect a 1/2 square foot hot spot (600° C) at altitudes of 10,000 feet. Hot spots of very high temperature are distinguished from warm terrain features by their spectral characteristics. A threshold (or multiple thresholds) is implemented at a standardized output signal level. Signals above the established threshold standard are considered fire targets. Mapping large fires requires sensitivity in the LWIR band, to allow identification of terrain features by the operator.

Both detection and mapping missions are accomplished at a variety of aircraft altitudes and speeds. The extreme requirement on sensor V/H (the velocity to height ratio) comes from the low altitude mapping mission, at 2000 feet altitude and 120 knots. The scanner V/H is sufficient to allow for 50% overlap on successive scans, which allows double detection of small fires and rejection of spurious noise spikes. The scanner V/H is sufficient to meet the requirements over the range of aircraft operational conditions.

Navigation Subsystem

The airborne Navigation Subsystem measures the aircraft position, attitude and heading for real-time determination of vectors to objects in the infrared imagery. The subsystem consists of a Global Positioning System (GPS) receiver for determination of aircraft position, and gyroscopes for aircraft heading and attitude determination. In addition, pressure altitude is measured for comparison and check of the GPS receiver. Continuous outputs from these instruments are interfaced with the airborne signal processing computer.

For attitude measurements, rate gyros are used and integrated to generate angular motion. For initialization, and for offsetting rate gyro DC errors, a pendulum is used and combined through a servo loop with a slow (>60 sec) time constant. The integration process and servo loop are implemented in firmware using a 16 bit microprocessor which samples the signals each 10 milliseconds. The use of a microprocessor in this situation enables the entire process to be integrated using standard off-the-self computer hardware. No special electronics will be necessary which will ease maintenance requirements and allow easy reproduction of the system. Attitude accuracy will be 0.5°.

Heading measurements will be taken with a directional gyro and north seeking compass. A servo loop will be implemented by combining the two outputs through differing time constants. Initially, both instruments will be read to define an arbitrary offset as determined by the start up condition of the gyro. The gyro will then serve as the primary output for heading. To correct for gyro drift, a servo loop will be implemented by differencing the gyro (plus offset) and the compass. The servo filter will be slow (>60 seconds) to properly average out short term compass errors caused by airplane lateral accelerations. The servo correction will then be implemented by varying the gyro offset. A microprocessor will be used to implement the servo function. Heading accuracies will be 1.0°.

Signal Processing Subsystem

The Signal Processing Subsystem consists of a specialized microcomputer, video processing electronics, video monitor and video recorder. The subsystem accepts the dual channel sensor data from the Sensor Subsystem, digitizes and mathematically combines them to produce quantized levels of thermal brightness values. The dual band data is combined in a manner which minimizes the possibility of false alarms caused by warm background objects (<600° C) and solar reflection. The Signal Processing Subsystem also interfaces with the Navigation Subsystem and Data Processing Subsystem. The brightness values which are determined to identify a fire or hot spot are tagged with navigation and ancillary sensor data for georeferencing by the Data Processing Subsystem.

The Signal Processing Subsystem is responsible for the real-time processing necessary to process the imaging sensor output. This includes the image combination of both wavebands, sensor calibration, fire identification in the image, and real-time operator input which identifies fire spots.

The Signal Processing Subsystem simplified block diagram is shown in Figure 3. Frame grabbers will be used to input the two channels of linescanner data for digital or analog input in real-time. The data is stored separately in two image buffers. The next sequence in the pipeline architecture utilizes a lookup table to generate the combined image (including thresholded image which identifies fire areas and brightness), and the original long waveband image for operator imagery display. Separate image buffers will then store this data as 1024 x 1024 pixel images. The operator imagery is then generated by displaying the long wave band in monochrome, with a red overlay indicating fire areas. Additionally, the thresholded data is also routed to a convolution filter which performs two minimum/maximum operations to eliminate noise spike false alarm, and reduce the data quantity to the data processing subsystem computer. A parallel data path from the frame grabber image buffers also allows brightness histogram processing for linescanner calibration. All of the video electronics will be fully compatible with standard monitors and displays. The pipeline architecture structure allows for the execution of complex computations with a speed commensurate with video imagery data rates (10 Mega pixels per second).

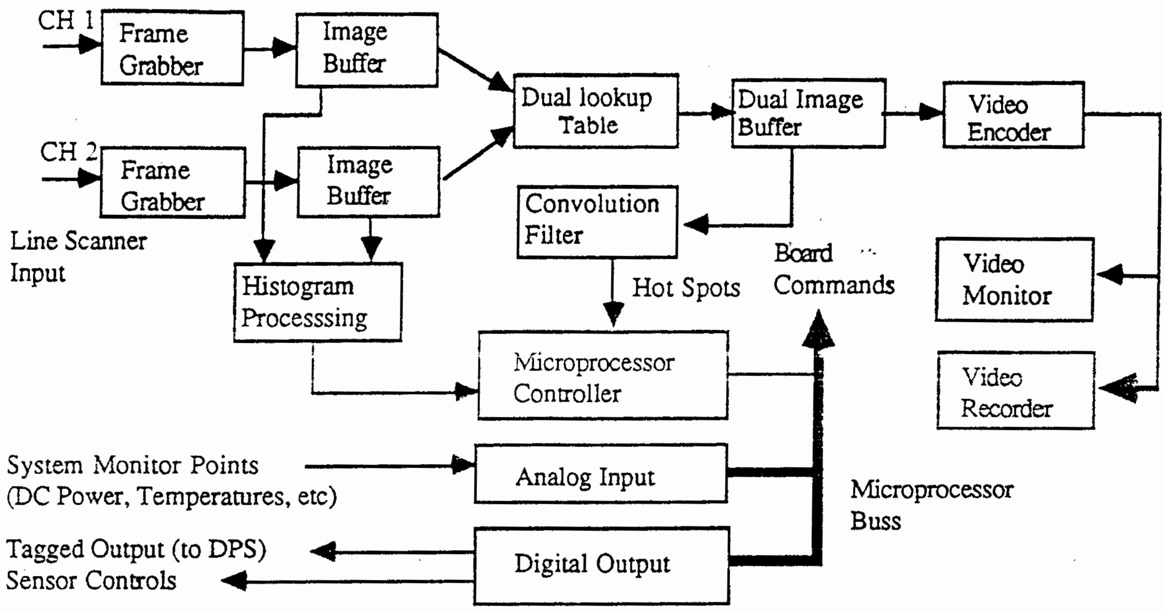

Figure 3. Airborne Signal Processing Block Diagram

Data Processing Subsystem

The Data Processing Subsystem consists of the computer, data storage, operator terminal, and software that is needed to georeference the tagged fire and hot spot data. The Data Processing Subsystem accepts the tagged fire and hot spot data and generates graphical data sets in order to compute the ground position of each point. In addition, this subsystem provides the primary control interface between the aircraft unit and the Firefly System operator. The subsystem graphical georeferenced output is the fire perimeter data sent to the Telecommunications Subsystem for transmission to the Ground Terminal.

The primary purpose of the Data Processing Subsystem is to collect fire location information from the Signal Processing Subsystem and to register it for plotting onto a standard United States Geological Survey map projection. As the Data Processing Subsystem receives the fire data from the Signal Processing Subsystem it will request navigation information from the Navigation Subsystem to determine the aircraft position and orientation at the time the data was collected. Once the Data Processing Subsystem has this information it will be able to calculate the true latitude/longitude coordinates for construction of the fire perimeter and hot spots map plot. At the request of the operator, the fire map will be transmitted to the Ground Terminal for plotting.

The operator interface will display the plot of the fire as data is received and processed. The interface will allow the operator to:

- Configure the Firefly system (switch currently displayed channel between channels A and B, change the automatic recalibration interval, etc.).
- Request the freeze frame and fire plot overlay to be digitally sent from the Signal Processing Subsystem
- Annotate the current plot for text or other markings to high-light features (e.g..streams, roads, fire breaks)
- Transmit the current plot to the Ground Terminal.

The Data Processing Subsystem software will be designed to continuously monitor the operator for inputs to perform the appropriate task upon receipt of an operator input. The software will continuously monitor the Signal Processing Subsystem for fire data and upon receiving fire data perform the following:

- Get current navigation information from the Navigation Subsystem.
- Scan the data for boundaries between different fire levels
- At each boundary determine the true latitude/Longitude location of the boundary using the navigation information and digital elevation data of the area.
- "Scroll" the current plot so that "old" data is lost to make room for new data.
- Add the boundary information to the current plot.

Telecommunications Subsystem

The Telecommunications Subsystem has consists of telemetry modems, transceivers and radios at both ends of the telemetry link, in the aircraft and at the ground terminal. The telecommunications interface will be a standard serial computer interface to eliminate the need for manual operation. The Telecommunications Subsystem will allow automatic data transmission and error checking when radio frequency line of sight conditions exist.

Ground Terminal

Telecommunications equipment, a microcomputer, plotter and power conditioning equipment are the components of the Ground Terminal. The Ground Terminal will be a portion of the Forest Service Incident Network (InciNet). InciNet is designed to interface with all Forest Service communication equipment by using standardized communication protocols and software languages. The purpose of the Ground Terminal is to receive the fire data from the Airborne System then generate a Firefly data output plot. The fire plot will consist of fire perimeter and hot spots with their corresponding intensity levels, and the operator annotations geographically referenced. The fire plots will be drawn on standard maps at the designated scale. The Ground Terminal microcomputer is the primary ground operator interface for initializing the unit and reporting status to fire management personnel.

CONCLUSIONS

The Firefly System will provide improved performance over current systems in terms of increased timeliness of data delivery, quantifiable accuracy, data consistency, reliability, and maintainability. The system will be the next generation of wildland fire mapping and detection systems. Firefly will meet or exceed the functional requirements for an advanced wildland fire detection and mapping system. The design concept provides flexibility by allowing the incorporation of both present and developing technologies. The system will make possible the acquisition and integration of requisite information into a high resolution, user-friendly system which will perform fire mapping and detection on a near real-time basis. The system will support potential non-fire, multiple-user reconnaissance missions through the incorporation of detectors outside of the IR spectral range.

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