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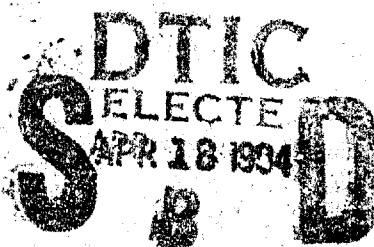
**DEVELOPMENT OF A MACHINE
VISION FIRE DETECTION SYSTEM**



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MARCH 1994

Final Report for August 1991 - April 1993

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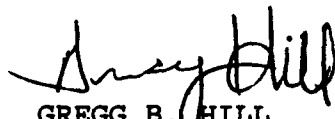
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PREFACE

This final report was prepared by Donmar Ltd., 901 Dover Drive, Suite 120, Newport Beach, CA 92660, under contract F08635-C-91-0217, sponsored by Wright Laboratory Flight Dynamics Directorate, Airborne Systems Branch, WL/FIVCF, Tyndall AFB, FL, 32403-5323.

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This report is submitted as a final report to a Phase II Small Business Innovation Research (SBIR) contract, and has been published according to SBIR directives in the format in which it was originally submitted.

This report has been approved for publication and release to the public by Donmar Ltd.

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SUMMARY

A. OBJECTIVE

The objectives of this program were to develop, test, fabricate and deliver a new type of fire detection system, based upon machine vision technology, which would significantly advance the state of the art of fire detection. The Machine Vision Fire Detection System (MVFDS) was designed to detect small hydrocarbon fires (e.g., 2 foot x 2 foot JP-4 jet fuel fire) at distances of 100 feet and greater, in less than one second. Other objectives included the ability to not only detect and alarm to the presence of a fire very rapidly, but to continue to monitor and determine its distance/location, size, growth, and threat in real-time. When the fire reached a predetermined size/threat (e.g., 16 square feet or more), the MVFDS would automatically release suppressant in the zone where the fire was located. The fire would therefore be extinguished with a minimum amount of agent, thus minimizing environmental impact and also minimizing any disruption of military operations, especially in operational aircraft shelters/hangars.

Detecting fires reliably and rapidly by determining the fire's physical, temporal, spatial, and spectral properties in real-time, was one major objective. This "physical properties" approach to fire detection differs entirely from that employed by current fire detectors. The MVFDS requires that many properties of fire must be satisfied. Current detectors require only one property to be satisfied, namely, intensity level and variations in a certain spectral band. Thus any nonfire source of radiation in the wavelength region where the ultraviolet (UV) or infrared (IR) detector operates, which has sufficient spectral irradiance (and flicker if required), will cause the detector to false alarm.

A second objective was immunity to nonfire events and objects, including those that IR and/or UV detectors may "see" as real fires and consequently false alarm. In order to "fool" the MVFDS into releasing suppressant, the object/event it "sees" must be in the color range of hydrocarbon flame; have a brightness greater than some threshold number; exhibit stationarity (the pixels of the original fire image remain in the same location frame-to-frame); the event/object must grow; the size of the event/object must be equal to or greater than the predetermined size for which the system is programmed to dump suppressant; and there must be spectral variations pixel-to-pixel in the image on a frame, as well as in the same pixel location in the image frame-to-frame. All these conditions must exist before the MVFDS recognizes an object/event as a fire threat. Even if the MVFDS alarmed to the presence of an object/event that is not a fire, it would not dump the suppressant unless the object/event was equal to or greater than the size of the fire event to which the system was programmed to discharge suppressant (typically 16-100 square feet).

A third objective was to provide a real-time video output which could provide for "man-in-the-loop" at a remote monitor, thereby offering such features as possible manual override of automatic suppressant release, or manual release of suppressant based upon human decision. If the suppressant system is zonal, only that zone where the fire is located would be activated.

B. BACKGROUND

The need for a fire detection system such as the MVFDS is driven by the need for reliability against false alarms, faster detection, and requirements to minimize the release of certain fire suppressants into the atmosphere. The problem of fire detector false alarms and accidental releases of suppressant is well known. The wavelengths in which current UV and IR detectors operate are often the same as the radiation emitted within military facilities by lights, aircraft, ground support equipments, tools, vehicles, and natural phenomena. Several of these sources of radiation may be present at the same time, thus possibly causing multi-wavelength UV/IR detectors to also false alarm. Fire detectors are expected to detect fires in the presence of such radiation emissions and at the same time to be immune to all of them at all times.

Fire detectors should be able to respond reliably to a fast growing fire in order to minimize physical injury and damage to valuable assets such as aircraft. Current detectors alarm to the presence of a fire of certain minimum size in about 5 seconds after the fire has reached the specified minimum size, not when the fire reaches the specified minimum size. Fires associated with pools of fuel, running fuel spills, and large quantities of combustibles, grow very rapidly, and can cause serious damage in less than 5 seconds if not suppressed. The MVFDS responds to the presence of small fires with an alarm in less than one second, and dumps suppressant when the fire reaches the threat size, not 5 seconds later, thus minimizing potential damage.

A DOD objective is to minimize harmful effects on the environment caused by the release of fire suppressant agents (such as halons) into the environment. The features of the MVFDS help to minimize the accidental release of these agents.

C. SCOPE

The MVFDS functions like a human. However, instead of eyes the MVFDS uses a camera. Instead of a brain used to store "knowledge" and process incoming information, the MVFDS uses a microcomputer and algorithms. By experience, we "instantly" know when we see a fire that it is a fire of certain approximate size and located at some distance. We recognize fire by its brightness, color, color variations, time-intensity changes, shape, flame edge (tongues) flicker, stationarity, and growth. We also know almost instantly that it is growing in intensity and size. If we could

activate an alarm when we first see the fire, and activate the release of suppressant when we determine the fire size to have reached threatening proportions, we would be a model of the MVFDS, but much slower, less accurate, and much more costly.

The MVFDS was developed using commercial off-the-shelf hardware components. Special algorithms were developed to measure certain unique physical, temporal, spatial, and spectral characteristics of hydrocarbon fuel fires. During the development process, the MVFDS was tested against many possible false alarm sources and actual fires set at the Edwards AFB fire facility. Operational testing was conducted at Tyndall AFB, where JP-4 fires were set inside test hangars.

The MVFDS hardware consists of a color charge coupled device (CCD) video camera, a real-time video image digitizer and processor called a Frame Grabber, a host microcomputer, alarms, and suppressor output interfaces. The color camera acquires 30 video frames per second and outputs RGB (red, green and blue) and/or NTSC RS170 analog signals. These signals are used to convert the video frames into digital computer data for processing. The video frame data is acquired upon command, digitized and transferred into the Frame Grabber's video memory. Up to four frames of digital color image data are stored in video memory on the Frame Grabber card. The card has a very high speed graphics microprocessor to process the image data at real-time speeds. The card is interfaced to an 80286 host microcomputer card which performs all the system level software functions such as initialization, built-in testing, program file operations, and Input/Output interfacing.

D. CONCLUSIONS AND RECOMMENDATIONS

The MVFDS is a significant advance in fire detection technology and provides the means to increase fire detection reliability and false alarm immunity. The detector is capable of identifying much smaller fires in much less time than is currently specified in AFR 88-15. The MVFDS was also shown to have many other applications, such as in aircraft engine bays and dry bays; ammunition plants; hydrogen and hypergolic fuel storage facilities; missile/Shuttle launch operations; overheat detection; mobile fire protection systems; crash rescue turret pointing; and fire protection of commercial facilities. It also has many nonfire applications such as intrusion detection; traffic conditions monitoring; and defect detection in manufacturing.

It is recommended that a full scale development effort be initiated to develop the MVFDS into an operational system for aircraft shelters/hangars, mobile fire protection systems, and in-flight aircraft fire protection.

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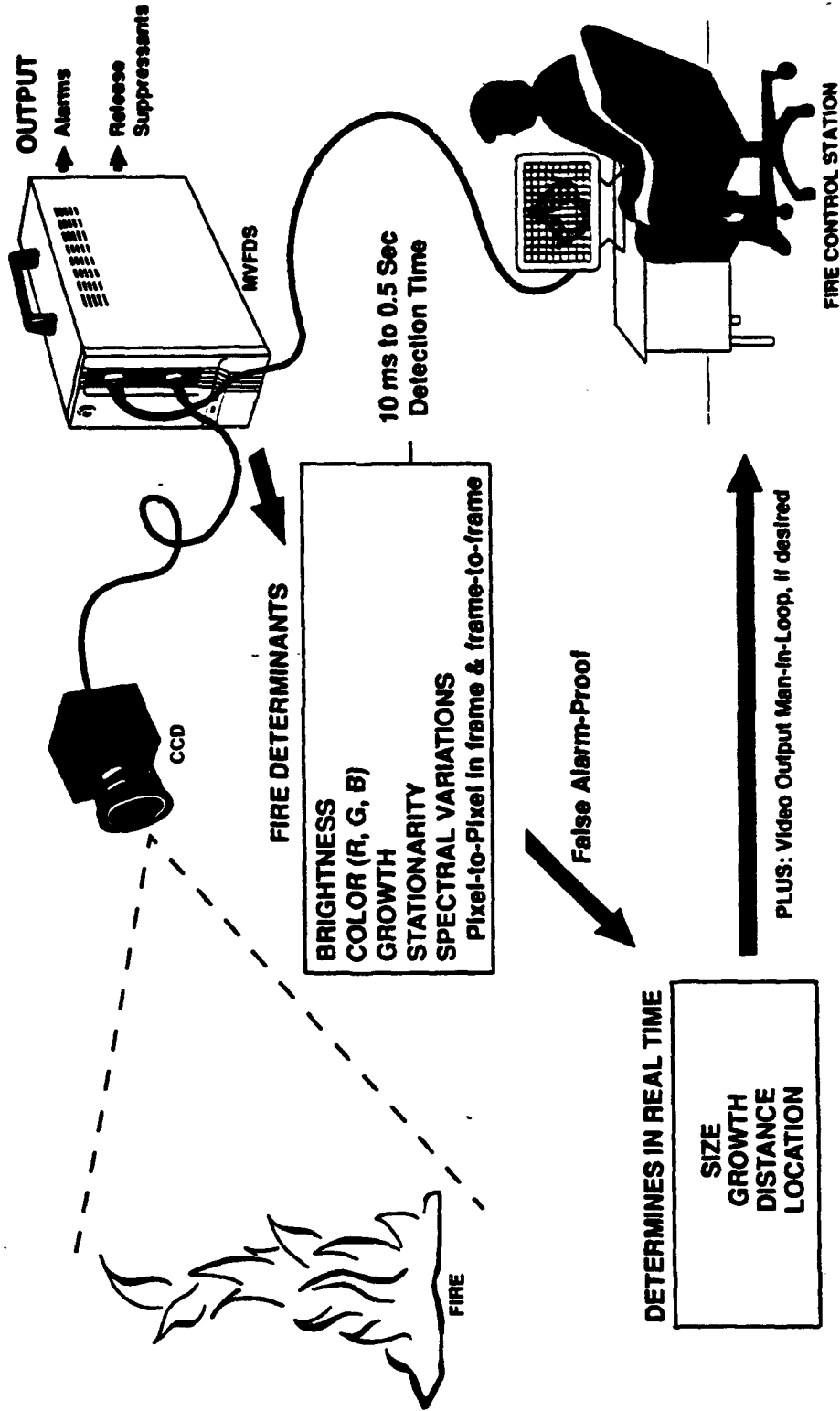
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DEFINITIONS OF ABBREVIATIONS AND SYMBOLS

A/D = Analog-to-Digital
AF = Air Force
CCD = Charge Coupled Device
CFC = Chlorofluorocarbon
DOD = Department of Defense
FOV = Field-of-View
HALON = A Type of Fire Suppressant
HAS = Hardened Aircraft Shelter
HORZ = Horizontal
HQ/AFCEA = Headquarters/Air Force Civil Engineering Support Agency
I/O = Input/Output
IR = Infrared
JP = Jet Fuel Type
LED = Light Emitting Diode
MBYTE = Megabyte
MHZ = Megahertz
MIL-STD = Military Standard
MM = Micrometer
MVFDs = Machine Vision Fire Detector System
NM = Nanometer
NTSC = National Television Standards Committee
OCCULUS = A Name-Brand Video Card*
PC = Personal Computer
R&D = Research and Development
RAM = Random Access Memory
RGB = Red, Green, Blue
ROM = Read Only Memory
SBIR = Small Business Innovative Research
SYNC = Synchronization
TARGA = A Name-Brand Video Card*
UV = Ultraviolet
VERT = Vertical
VGA = Video Graphics Adapter
WL/FIVCF = Wright Laboratory/Flight Dynamics Directorate Vehicle
Subsystems Division Air Base Systems Fire Protection and Crash
Rescue Systems Section
 \int = Integral
 I = Iota
 λ = Lambda
 μ = Mu

*Note: The mention of name-brand components does not constitute endorsement.

MACHINE VISION FIRE DETECTION SYSTEM



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SECTION I

INTRODUCTION

A. OBJECTIVES

The objective of this Phase II SBIR project was to demonstrate that a fire detection system, based upon machine vision technology, could be developed and proven to operate according to the conclusions made in the Phase I SBIR feasibility project and documented in the Phase I Final Report (Reference 1). The application of the detector was intended for Air Force aircraft hangars, shelters, fueling docks, maintenance facilities and related aircraft operations. The basic performance goals were (1) to exceed the current Air Force Specification 88-15 to detect a 10-foot x 10-foot JP-4 pan fire at a distance of 150 feet in 5 seconds or less after the event reaches the specified size, and (2) to exceed the specifications in Air Force Technical Letter ETL 90-09, dated November 2, 1990, to detect a 2-foot x 2-foot JP-4 pan fire at 100 feet in 5 seconds or less. The efforts discussed herein accomplished the goals of this SBIR Phase II Program.

Additional goals of this project were to develop a fire detection system that is immune to false alarms, detects small fires at distances of 100 feet or more, determines the fire location and distance, determines the fire's size/growth-rate in real time, and detects the fire in less than 1 second. In addition to meeting these goals, several capabilities were demonstrated to be fallouts of the detector's technical functions. These capabilities include: (1) ability to provide video monitoring of the fire scene simultaneously with the fire detection mode, thus allowing manual override if desired (this applies to both ground facility applications as well as to in-flight aircraft fire protection applications); (2) ability to have input into the logic process other, previously installed, detectors, such as UV or UV/IR; (3) ability to determine location of fire and thus release suppressant only in the region where the fire threat exists (zonal suppression), thus minimizing deleterious environmental impact; and (4) the potential of operating in a much faster mode, near 10 milliseconds, thereby having the ability to detect fast reacting events such as munitions penetration in aircraft dry bays and engine bays, and pyrotechnic materials fires/explosions.

B. BACKGROUND

A continuing goal of the Air Force is to advance the technology of fire protection by increasing the performance of fire detection and suppression systems. Another goal is to minimize the deleterious effects of agents such as Halon 1301 and 1211 on the atmosphere. Together, these goals are directly related to reliability of fire protection systems, especially against false

alarms and accidental releases of extinguishing agents. In turn, all these goals are related to cost impact and the ability of the Air Force to maintain readiness of mission-essential weapon systems and to minimize their downtime due to extraneous problems with fire protection systems.

False alarms of installed systems in Air Force facilities, as well as other DOD facilities, have been a problem with fire-detection and fire-suppression systems for years, although the frequency of occurrence of major false alarms/suppressant dumps has decreased in recent years due to improvements in detection techniques. This decrease has been associated with the increased attention given by industry to their detector's response characteristics. Although false alarms have decreased in number, they continue to occur.

A recent study performed by Donmar for the Air Force [Reference 2] indicated that it is relatively easy to duplicate or exceed the spectral irradiance values of the specified threshold fire size and distance for detection from common sources of UV and IR. In other words, there is enough radiation flux in the spectral bands where fire detectors commonly operate to "fool" a detector into "believing" that a fire of specified size and distance exists within the detector's field-of-view. Sources as simple as a 150-watt incandescent lamp, a hot body such as an exhaust pipe, and a 300-watt Quartz Halogen Tungsten lamp, at distances of 10-20 feet from the detector, could satisfy the spectral energy requirements of the detector to mistakenly identify the signal as emanating from a 2-foot x 2-foot JP-4 fire at a distance of 100 feet or less.

Ultraviolet and infrared detectors measure the energy flux in specific wavelength bands. These may be either broad or very narrow, depending upon the nature and properties of the fire's emission characteristics. Hydrocarbon fires also emit in the visible region in red, yellow, and orange colors. These emissions, as seen by the human eye or a video camera, show also many features such as color variations of the flame front; growth of the event; stationarity or relative non-movement of the location of the pixels from the event onset through event development, and "flicker." Instead of relying only on intensity measurements in the UV and/or IR, where such radiation wavelengths can be emitted from a multitude of sources, machine vision fire detection relies on the visible spectrum, but not solely on intensity. Instead, it relies on physical, spectral, temporal, and spatial properties that are unique to fire and as deduced to be unique by the human process of "seeing" and "deduction" that the object is a fire.

It was, therefore, a major consideration to develop a Machine Vision Fire Detection System that provided intelligent decisions based upon actual properties of fire events to provide immunity to nonfire false alarm sources. In other words, the MVFDS was developed to emulate a human's process of determining the physical,

temporal, and spatial characteristics of an object or phenomena, comparing and analyzing such information with stored knowledge, and rationalizing the nature, size, location, and threat of the event.

The "ideal" fire detector could be described as a human being with full field-of-view of the area to be protected, who never gets tired and who can react to provide a decision and manual response within a "blink-of-an-eye" (0.1 seconds). The MVFDS functions like this ideal detector. By experience, we "instantly" know when we see a fire that it is a fire of certain approximate area extent, located at some estimated distance, and possibly associated with some object. We recognize fire by its brightness, color, color variations, time-intensity changes, shape, flame edge (tongues) flicker, stationarity, and growth. We also know almost instantly that it is growing in intensity, size, and location. If we had an electrical switch in our hand that could be activated when we first saw the fire to sound an alarm, and another switch that could release the suppressant when the fire size has reached threatening proportions and should be automatically extinguished, we would then be a model of the machine vision technology fire detector, but much slower, less accurate, and much more costly.

Machine vision technology provides the means by which information can be extracted automatically by computer processing of video imagery whereby certain preprogrammed patterns, spectral properties, or changes are searched for and, if found, provide the basis of some form of deduction and/or decision. The technology enables reliable and rapid discrimination of objects and phenomena from a large variety of similar objects and phenomena which can have almost identical spectral features in the visible region.

The application of machine vision technology, via artificial intelligence, pattern recognition, and computer image processing, to target recognition/identification and/or change detection is not new. The DoD has used this technology in reconnaissance for years and the Landsat Satellite data are often processed with such algorithms to inventory forests and crops, determine land use, assess environmental impacts, map geologic features, and identify possible locations of natural resources. In recent years, machine vision technology has been successfully applied to a wide range of problems. Automatic visual inspection has led to significant increases in industrial productivity [Reference 3]. Independently operating vehicles have been guided by artificial vision systems [Reference 4]. Many robotic applications have been simplified by machine vision [Reference 5]. In addition, machine vision techniques have been used to aid in the interpretation of medical images [Reference 6].

The approach taken to fire detection is derived from physical models for the formation of images of fires and other stimuli. These models incorporate the physical characteristics of both events in the "world" and image sensors. Various properties of

fire can be derived from these physical models using color image measurements. These can be used reliably to distinguish fires from other events. These properties can be computed at high-speed and together with a decision procedure form the basis of a fire detection system. This system can rapidly identify fire events (in the 0.5 second time range) and compute the corresponding size and location of the event in the scene. The effectiveness of these properties for fire identification has been demonstrated analytically and experimentally on real fires, sequences of color images of fires, and possible false-alarm sources.

The MVFDS imaging system consists of a color charge-coupled device (CCD) camera and associated optics. The three dimensional scene is imaged as a spectral irradiance pattern onto the focal plane of the device. This spectral irradiance is proportional to the spectral radiance over corresponding patches in the scene. The CCD imager consists of a two-dimensional array of collection sites that are sensitive to light. Color filters are positioned over spatially adjacent collection sites to measure the intensities of red, green, and blue light at each location in the image. From these measurements, the camera electronics produce three analog video signals corresponding to each of the component colors. Each of these signals is quantized both spatially and in amplitude by a frame grabber to produce a digital color image. For the hydrocarbon fire application, spatial quantization is typically into 480 rows and 512 columns and amplitude quantization is between 5 and 8 bits per color per pixel. The frame grabber is designed to acquire digital color images and store them in computer memory at the standard video rate of 30 frames per second. Analyses have indicated, however, that for general fire detection the throughput required by the frame grabber is about 10 or less frames per second. Once in computer memory, the color images may be analyzed by a digital processor to detect fire events. In applications such as pyrotechnic fires, it appears from existing technology that very fast speeds can be attained with no risk.

The color images acquired by the frame grabber are represented hierarchically as a set of two-dimensional blocks that are processed individually by the fire detection algorithms. Each block corresponds to a specific area in the monitored scene and the size of each block is proportional to the corresponding area in the scene. Such structure increases efficiency by allowing the fire detection system to focus computational resources on regions of interest in a scene without requiring complicated addressing schemes. As frames are acquired, the system control structure incrementally updates the current status and characteristics of each block. Once a contiguous array of blocks is identified as corresponding to a fire event the system will activate an alarm, if required. When the number of contiguous blocks are equivalent to a specified fire size, the system will take the appropriate programmed action, such as an automatic release of suppressant at the location of the fire.

A set of visible features that characterize fires and allow robust discrimination of fires from other visible stimuli has been derived from physical models. The features include brightness, color, texture/spectral variations, flicker, and stationarity. Numerical measures of these features can be computed from color image sequences at high speeds. Inappropriate values of any of these measures for a stimulus rapidly eliminate it from consideration as a fire event. Stimuli which exhibit appropriate values for each of the selected features are reliably classified as fires.

After each color frame is acquired, the system control structure examines each image block and computes feature measures. After each frame is processed, blocks marked as LIVE have demonstrated feature values that indicate the possibility of a fire and blocks marked as FIRE have demonstrated feature values that indicate a fire. Other blocks are marked as INACTIVE. A history is kept for LIVE and FIRE blocks including parameters such as event size and statistics necessary to estimate frame to frame spectral flicker after subsequent frames are acquired. The data structure containing these block histories is the only information that must be retained from frame to frame allowing minimization of system memory requirements.

As blocks are processed for each frame, feature computations are ordered to ensure that system computation is focused on blocks that require the most attention. Brightness is evaluated first, by examining the fraction of block pixels exceeding a threshold in the red band. Blocks failing the brightness test are marked INACTIVE and are not tested further. The color test examines the fraction of block pixels having red, green, blue (RGB) values that fall within a certain volume in RGB space that is characteristic of fires. This volume is large enough to represent physical variations in fire color and brightness. Block texture is computed by examining local spatial variation in pixel values. Block flicker is computed by considering frame to frame variations in color pixel values. Computed texture and flicker values are compared to the fire model. Since the system partitions images into spatially fixed blocks, nonstationary events which rapidly leave their previous location are easily eliminated from consideration as fire events.

After the blocks of each new frame are labeled, the system locates contiguous blocks with FIRE labels. If these blocks correspond to a sufficiently large area in the scene to indicate the fire has reached a predetermined threshold size or threat, the system responds with the specified required action (e.g., agent dump).

This process may seem long, but in fact it occurs in tenths of a second using conventional, commercial off-the-shelf hardware. For the application to detection of pyrotechnic/propellant

fires/explosions the algorithms would be simplified according to the physical characteristics of the detonation/fire event. These data are available in high speed color video and can be used to refine existing and develop new algorithms.

The application of this technology for fire identification is new. It is a major extension of the integrated use of charge coupled devices, frame grabbers, and computer video image processing. The detector, including its hardware and software, as described herein, is based upon the patent #5,153,722 issued to Donmar Ltd. on October 6, 1992.

Machine vision, then, offers a new technology approach to fire protection (as well as other applications), which is much different from the conventional fire detection technology that continues to rely upon UV and IR intensity measurements and the application of signal processing/conditioning to increase specificity.

C. SUMMARY OF PROJECT

The recommendations and conclusions of the Phase I SBIR Project [Reference 1] formed the basic objectives and approach of this Phase II effort. From the results of the feasibility study, this effort was dedicated to developing the necessary software and hardware to implement the concept of fire detection originally developed in the Phase I SBIR proposal and Phase I Final Report, and as outlined by the concepts included in Patent #5,153,722. The detector performed in tests as specified in the performance criteria. It responded correctly to fire and did not respond to nonfire events or objects. The detector was not subjected to detailed field testing, as such testing is planned to be performed by the Air Force HQ/AFCEA (recently changed to WL/FIVCF), Tyndall AFB, FL.

The concept demonstrated in Phase I was developed into an operational product in Phase II. Both algorithms and hardware were developed and tested. The approach taken was to use "off-the-shelf" commercial hardware where possible in order to reduce new development costs and technical risk. A functional product was developed that conformed to the basic performance specifications quoted herein. Commercial-type computer boards were used that contained the basic frame-grabbing, storage, computer processing, and I/O's. Also, a standard computer enclosure, with its own power supply, was used to house the electronics, video CCD camera, and related items. The overall size of the enclosure was 15 inches x 10 inches x 5 inches. The camera electronics was mounted inside the enclosure; the CCD detector was mounted either on the outside of the enclosure or via a connector to a 25-50 foot cable, thus allowing the detector to be either hard mounted on the casing or removed from the processor unit by some distance.

Two models of the MVFDS were developed. One is a single

detector with the option, as stated above, of either being integrated into the enclosure or being removed from the processor enclosure to distances up to 50 feet. The second model has two CCD cameras, both connected to the processor unit via cables. This unit could cover a very large area with two camera units, both linked to the same processing electronics.

The product which was developed requires further refinement, value engineering, and production design to optimize its commercial market potential. As a military application product, the detector may have to be designed with military standard components and may be required to pass certain military standard environment and quality specification tests. This depends, however, upon the application. As a fire detector for ground-based hangar/shelter applications, these military standards are not required; however, in a military/commercial aircraft application they would have to be met. It would be prudent to design the product for minimum cost, regardless of the application. This would mean dedicated electronic boards and, perhaps, the use of VLSI technology. The camera would also be modified to include only those parts absolutely necessary to the machine vision fire detector function.

The detector unit could be developed for many applications requiring fast response (in milliseconds) to slow response (in 5-10 seconds, or more). The software would be easily modified, to adapt from one application to another. Also, the size of the entire unit could be made very small, depending upon the need. A size of 6 inches x 3 inches x 6 inches is certainly practical. The ability to use the device in a video mode, simultaneously with change detection, fire detection, explosion detection, intrusion detection, and many other applications, opens a wide variety of possible commercial and military uses.

SECTION II

REQUIREMENTS

A. FIRE DETECTION AND CHARACTERIZATION

Fire characteristics depend upon a very broad set of parameters, including the nature and properties of the fuel/substance. The descriptive properties may extend over categories of static and active properties as measured across spectral bands from the UV through the visible and into the infrared. Flame and smoke are obvious characteristics of hydrocarbon fires. The mode of fire detection discussed herein is based upon the properties of flame as detected and analyzed by the machine vision fire detection morphology, and only pertains to the visible part of the electromagnetic spectrum (although flames are also associated with emissions in the UV and IR bands where other older technology detectors operate). Although the MVFDS described herein pertains to the visible spectrum, the patented concept can also utilize the IR spectral band in particular applications.

Hydrocarbon fires produce a large amount of spectral emission in the mid-infrared, typically peaking in the wavelength region around $1.7\mu\text{m}$. The IR emission curve resembles that of a typical bell-shaped black body curve from about $0.5\mu\text{m}$ to $4.0\mu\text{m}$, until it reaches the $4.3\mu\text{m}$ emission "spike" associated with CO_2 . This specific emission spike is very large and occurs in the "window" of the solar atmospheric absorption spectrum where the sun's emission in this band is absorbed by the atmosphere. This further accentuates the signal-to-noise (background) ratio and greatly facilitates the detection of hydrocarbon fires. It is not unusual then, that all fire detectors operating in the IR use this narrow spectral band. The emission, however, of $4.3\mu\text{m}$ radiation is not unequivocally associated with fire. It is emitted, to some degree of intensity, by all "hot" bodies, including such common items as vehicle exhaust pipes, personnel heaters, hot lamps, welding operations, and aircraft exhaust effluent (including afterburners).

Hydrocarbon fires also produce distinct emissions in the ultraviolet, which peaks near 310 nm. The atmosphere has little absorption effect on UV in the near UV region but is rather opaque to UV in the 185 nm - 260 nm region. Although the spectral irradiance in this band is very low compared to that at higher wavelength bands, it is the region where UV fire detectors are designed to operate. The major reason for selecting this UV band is because of the "Geiger Mueller"-type of operation which is utilized by UV vacuum tubes, and because the background solar UV in this band is absorbed by the atmosphere, thus minimizing the background.

When a photon strikes the cathode, usually tungsten, an electron is emitted. Tungsten has a work function that will allow, as a minimum, a photon of wavelength $0.245\ \mu\text{m}$ (245 nm) to cause an electron to be emitted from the cathode. The emitted electron is drawn to the positively charged anode and, enroute, strikes gas molecules which in turn are ionized, thus resulting in a current between cathode and anode. An avalanche/discharge occurs which can be interrupted by switching the power on and off or by reversing the charge on the cathode and anode.

The glass envelope, usually quartz, is opaque to wavelengths shorter than about 185 nm. Therefore, the spectral UV sensitivity of the UV detector is usually between 185 nm and 245 nm, although the cutoffs extend to longer as well as shorter wavelengths. This type of detector is a relative intensity detector, which cannot discern the nature of the source, direction of the source, distance of the source, or spectral irradiance of the source. It cannot discriminate spectral energy flux (spectral irradiance) because it will respond to all energies equal to or greater than the specific work function of the cathode and to any source that causes ionization of the fill gas(es) to occur.

One problem with this type of UV detector is that it is sensitive to extraneous UV, charged particles such as cosmic rays, and ionizing radiations. To circumvent this sensitivity problem, the electronics are usually programmed to activate an alarm/suppressant dump only when the count rate reaches some minimum level over some gated time sequence, which is normally above the estimated background count rate or other possible count rates caused by nonfire sources of UV.

Although both IR and UV emissions in the 185nm-260nm and $4.2\mu\text{m}$ - $4.5\mu\text{m}$ bands are associated with fires, these same emissions are also associated with a multitude of nonfire sources that may "fool" the detector's logic into signalling "fire" when the source may be something as simple as a quartz tungsten halogen lamp.

Each type of detector, UV, visible, and/or IR, responds to some different "signature" or characteristic of fire/flame. The major difference, however, between UV and IR detectors, and visible machine vision detectors, is that UV and IR detectors measure only relative intensity of the radiation in some spectral band and can not discern the nature of the source, or its location, distance, or size. The detectors only know that some source of the characteristic UV and/or IR radiation is present somewhere, perhaps not even within its field-of-view (scattering). A Machine Vision detector deduces that a fire exists by determining the physical, spatial and temporal characteristics of the "event" and comparing them to stored information which is uniquely descriptive of fire.

Fire characteristics include (1) a bright object; (2) color distribution in red, green, and blue planes that is descriptive of

the flame/fire type; (3) growth of the event from time of ignition; (4) stationarity of the event from time of onset (the base pixels of the event at fire ignition do not move significantly in time); (5) different spectral features for pixels in a single image; and (6) different frame-to-frame spectral content of pixels providing a "spectral flicker" of very high frequency. When all these characteristics are present, the machine vision detector determines the event to be fire. It knows the distance of each scan line (set at time of mounting) and thus the size of each pixel per scan line. Integrating the number of pixels in the "fire object" the size of the event is thus known, as well as its growth rate.

The basic difference between both types of fire detectors is that UV and/or IR detectors are intensity measuring devices while machine vision acts in the same manner as the human process of sight, comparison to stored memory/experience, recognition, and deduction. This overall process is more exact and includes, to a large degree, most of the specific visual properties of flame/fire events. It is also less likely to be fooled by any nonfire source unless it contains all of the above properties.

If the machine vision approach to fire detection proves susceptible to some sort of nonfire phenomenon, the reliability against false alarms can still be much greater than UV and/or IR fire detection alone, by simply requiring the additional presence of either the UV or the IR spectral band radiation emissions that are associated with fire. If this combination of visible-machine vision and UV detection is implemented, the reliability against false alarms would be very large, although it is already large without the UV. Should the UV detection mode respond with a "fire" signal, when the machine vision fire detector says "no", then the machine vision decision would override the UV's because it has a much greater reliability of fire detection than UV detection alone. The use of UV with machine vision is only mentioned here to account for those situations where UV/IR detectors may have already been installed in a facility to protect some major resource, such as a B-2 Aircraft hangar. The addition of machine vision detection to the facility could enhance the overall fire detection and false alarm discrimination of the entire system by adding an "AND" to the fire detection logic. It would also provide the man-in-the-loop function by allowing realtime video as well as fire protection monitoring.

B. TECHNICAL PERFORMANCE SPECIFICATION

The recommended performance specification for a full scale-developed MVFDS is given in Appendix I. The actual specification would of course be determined by the Air Force for specific applications.

SECTION III

TECHNICAL APPROACH

A. PHYSICAL MODEL-BASED MACHINE VISION

In the early 1970s, Machine Vision emerged as a discipline separate from Pattern Recognition. Early work focused on using geometric imaging relationships to recover 3-D scene information from 2-D image data. Even today, most work in Machine Vision is based on the geometric analysis of image data and regions by treating the sampled image spectral irradiance function $I(x,y,\lambda)$ using simple statistical and geometric models. Unfortunately, such analysis is of limited use for complex images because image irradiance is not accurately described using simple image-based models. Rather, measured image spectral irradiance depends on the illumination environment, the emitting and reflecting characteristics of objects in the field-of-view (FOV), and the properties of sensors. Thus, modeling images accurately requires an understanding of the physics of image formation.

Machine vision researchers have recently recognized the importance of developing algorithms from increasingly sophisticated physical models [Reference 7]. Such an approach holds considerable promise since the physics of image formation link the world that must be understood to the image that is input to a vision system. Progress has been made in modeling the properties of surfaces, illuminants, and sensors to exploit phenomena such as color, shading, highlights, polarization, and interreflection for image interpretation. The physical models have led to new algorithms for segmenting images and recovering properties of surfaces such as shape, spectral reflectance, and material.

The use of physically motivated models for algorithm development provide several important advantages. First, algorithms can be derived from these models that recover physical properties of the objects in the scene and interpret images based on these physical properties. Second, if scene knowledge is available describing, for example, the color of illumination or the depth of objects, it can be used to constrain parameters of the models to improve performance. Third, it is possible to characterize the class of scenes that can be processed with a certain degree of accuracy when using these models. This characterization is important in guiding potential users in the selection of models and algorithms for applications. Such an approach is much more appropriate for fire detection than heuristic approaches such as using artificial neural networks since it is difficult to predict or characterize the performance of systems based on such methods.

The algorithmic approach taken to fire detection is derived

from physical models for the formation of images of fires and other stimuli [Reference 8]. Much of the effort in this project has been devoted to developing these physical models and deriving algorithms that can estimate parameters of these models from images. Large amounts of real video data were analyzed during the construction of these models. The models incorporate the physical characteristics of both events in the world and image sensors. Various properties derived from color image sequences can be used to distinguish fires from other events. Algorithms have been developed that can compute these properties at high-speed and together with a decision procedure form the basis of the fire detection system. This system is capable of rapidly identifying fire events and computing the corresponding size and location of the events in the scene. The effectiveness of these properties for fire identification has been demonstrated on many sequences of color images of fires and false alarm data. The algorithms have been implemented in real-time hardware to provide a complete fire detection system. Additional algorithms not currently implemented within the system have been developed and will be exploited in future versions of MVFDS and for other applications as necessary.

Physics-based Machine Vision has only been applied to images of reflecting surfaces [Reference 9]. Research has been based on reflectance models that describe the properties of reflected light from a description of the geometric and radiometric properties of illuminants and surfaces. In addition, this analysis has been concerned primarily with man-made objects. Nevertheless, this approach has led to important new algorithms for image segmentation, material classification, and surface shape estimation.

In this work, the physics-based model has been reworked and applied to fires which emit radiation rather than from reflecting surfaces. This problem is fundamentally different from the reflective surface situation and presents important simplifications and technical challenges. The most significant simplification is that, unlike reflecting surfaces, the appearance of fires is relatively insensitive to the spectral and intensity properties of the ambient illumination. Thus, it is not necessary to include computationally intensive color and brightness constancy algorithms with MVFDS. Such algorithms are necessary to compensate for illumination properties in systems designed to recognize reflecting surfaces in environments with unconstrained illumination. On the other hand, fires provide much more visual complexity than most reflecting man-made objects. Fires exhibit complex geometric structures as well as highly textured spectrally varying radiometric patterns. Moreover, the complex visual structures vary rapidly with time.

In this project, image observable characteristics of fires were derived from physical models. New physics-based algorithms that exploit these characteristics are described later.

For many years, Machine Vision has used color images. Even early Landsat imagers used several visible and infrared bands. This technology was used to classify regions of the earth according to stored spectral signatures. In this early work, color mainly provided additional features for input to a pattern classifier. Often, these color features improved classification accuracy. Unfortunately, in these systems color was treated as a generic feature along with others such as geometry and texture. By ignoring the physical attributes of color, such systems did not reach their true potential.

Since the onset of physics-based Machine Vision, researchers have realized the importance of using physical models to exploit color information in image understanding. The analysis of these models has led to several uses of color that extend the capabilities of Machine Vision systems using only intensity images. For example, color can be used to distinguish material changes in a scene from other physical events. Some events amenable to analysis using color images are shadows, surface shading, highlights, and interreflection. Physical fire models also allow uses of color information that improve the capabilities of detection over only intensity processing. The large consumer market for color video cameras has reduced the price of color cameras so that they are easily within reach for most Machine Vision applications.

The imaging system used in MVFDS consists of a color CCD camera and a frame grabber. A color pixel measurement at (x,y) , in the image is modeled by the triplet (S_R, S_G, S_B) where

$$S_R(x,y) = \int I(x,y,\lambda) f_R(\lambda) d\lambda \quad (1)$$

$$S_G(x,y) = \int I(x,y,\lambda) f_G(\lambda) d\lambda \quad (2)$$

$$S_B(x,y) = \int I(x,y,\lambda) f_B(\lambda) d\lambda \quad (3)$$

and where $I(x,y,\lambda)$ is the incident spectral irradiance at (x,y) and $f_R(\lambda)$, $f_G(\lambda)$, and $f_B(\lambda)$ are the response of the red, green, and blue sensing elements respectively. The response of a sensing element is equal to the transmission of the color filter (in this case red, green, and blue) times the quantum efficiency of the CCD.

Equations (1)-(3) illustrate how color cameras compress the vast amount of information in the incident two dimensional spectral irradiance signal $I(x,y,\lambda)$. By using the RGB color filters, a continuous function of wavelength is mapped into three numbers at each pixel. Such sampling is analogous to the spectral sampling in the human retina where three cone types based on distinct photopigments encode color signals before transmission to higher levels of processing in the brain. Such compression is necessary to limit to a manageable level the amount of input that must be processed by a biological or machine vision system.

A stochastic model for the spectral radiance of a fire in the scene has been developed according to

$$E(x',y',z',\lambda,t) = E(\lambda) + V(x',y',z',t,\lambda) \quad (4)$$

where (x',y',z') denote coordinates in the scene projecting to (x,y) in the image, the function $E(\lambda)$ describes the mean spectral radiance of a fire, and the process $V(x',y',z',t,\lambda)$ quantifies spatial variation and temporal variation (flicker) in the intensity and color of a fire. In terms of this model, the measured pixel values for a fire at time t are given by

$$S_R(x,y,t) = \int E(x',y',z',\lambda,t) f_R(\lambda) d\lambda \quad (5)$$

$$S_G(x,y,t) = \int E(x',y',z',\lambda,t) f_G(\lambda) d\lambda \quad (6)$$

$$S_B(x,y,t) = \int E(x',y',z',\lambda,t) f_B(\lambda) d\lambda \quad (7)$$

Using this model, the image of a fire will exhibit the properties of high intensity, characteristic color, and characteristic flicker. A fire event that must be suppressed will exhibit each of these three properties as well as a size and growth rate above specified thresholds. Algorithms that estimate these properties of fires from color image sequences will be presented in Section IV-C-1.

B. TESTING PROCEDURES

Given the complexity of the physical world, testing with real images sequences is useful to evaluate the accuracy of models and the performance of algorithms. As a part of this project, the component algorithms and the fire detection system as a whole have been systematically tested on jet fuel fires and false alarm sources for a wide range of scene configurations and environmental conditions. In the early stages of development, this testing led to new insights and refined fire models and algorithms. The behavior of each system module has been evaluated separately and interactions between modules have been carefully understood. Experiments with the integrated modules have been used to evaluate the performance of the fire detection system as a whole and the dependence of overall performance on input, models, and algorithms. These experiments have demonstrated the performance of the system on a wide class of scenes. Examples of the results for some of the tests are given in a later section.

Most of the test data were derived from color videos obtained according to detailed plans at Edwards Air Force Base and other sites. Before actual test data was gathered, preliminary data was used for camera calibration and to optimize camera settings such as color balance, lens aperture, and integration time. Several parameters were carefully varied during video data collection. These parameters included fire size, fire distance, and scene composition. Tests were conducted at various times of the day and

night with a range of false alarm sources. These false alarm sources were selected to have visual properties such as brightness, color, and motion that as much as possible resembled actual fire events.

For testing purposes, algorithms were implemented on a PC system equipped with a Truevision Targa frame grabber. This system was used for MVFDS testing on the video data obtained at various sites. The Targa system enabled the simulation of system operation at different frame capture rates. Since system code was compiled and run on the PC host, modifications and parameter changes could be rapidly made and evaluated. This testing allowed system development and performance quantification over a range of situations and permitted parameter refinement for the various algorithms.

After system verification using the Targa-based system, the algorithms were ported to the real-time Coreco Oculus hardware. This system allowed the algorithms to be further tested on live and video events. This testing operated at the actual frame rate of the delivered system and allowed accurate system performance characterization. Oculus-based testing also permitted a characterization of the actual time required for system response to a range of stimuli.

C. TECHNICAL ACCOMPLISHMENTS

1. ALGORITHM DEVELOPMENT

a. Overview

The new physical model-based algorithms that are used to discriminate fires from other objects/phenomena have been incorporated into MVFDS. This system is designed using spatial image representations that support efficient processing. Computation is organized so that the system focuses processing power on image regions that exhibit fire-like characteristics and rapidly rejects regions that do not. This approach allows the system to monitor continuously a large field-of-view (FOV) without requiring expensive high-speed processors.

The fire detection system is divided into four components: (1) division of the image into a grid, (2) identification of grid regions as possible fires, (3) labeling of connected fire components, and (4) interpretation of the labeled components. The division of the image into a grid is performed off-line in terms of the scene geometry and properties of the imaging system. During operation, the system processes color frames acquired at 0.1 second intervals. For each frame, the program cycles through the grid rectangles and performs tests to identify rectangles containing fire. After this testing the system passes control to the connected component analysis. If adjacent

grid rectangles are determined to contain fire, they will be represented as part of a single fire event. Following connected component analysis, the event interpretation component of the system measures event growth using previous event data. After event interpretation, the system has the option to enter an alarm mode, a suppression mode, or to continue with normal operation. The alarm mode indicates the presence of a small fire that does not pose an immediate threat but one that should be monitored. If an event exhibits sufficient size and growth, the system activates automatic suppression. If no fire events are detected, the system continues processing frames in normal operating mode. Figure 1 depicts a flowchart of system operation.

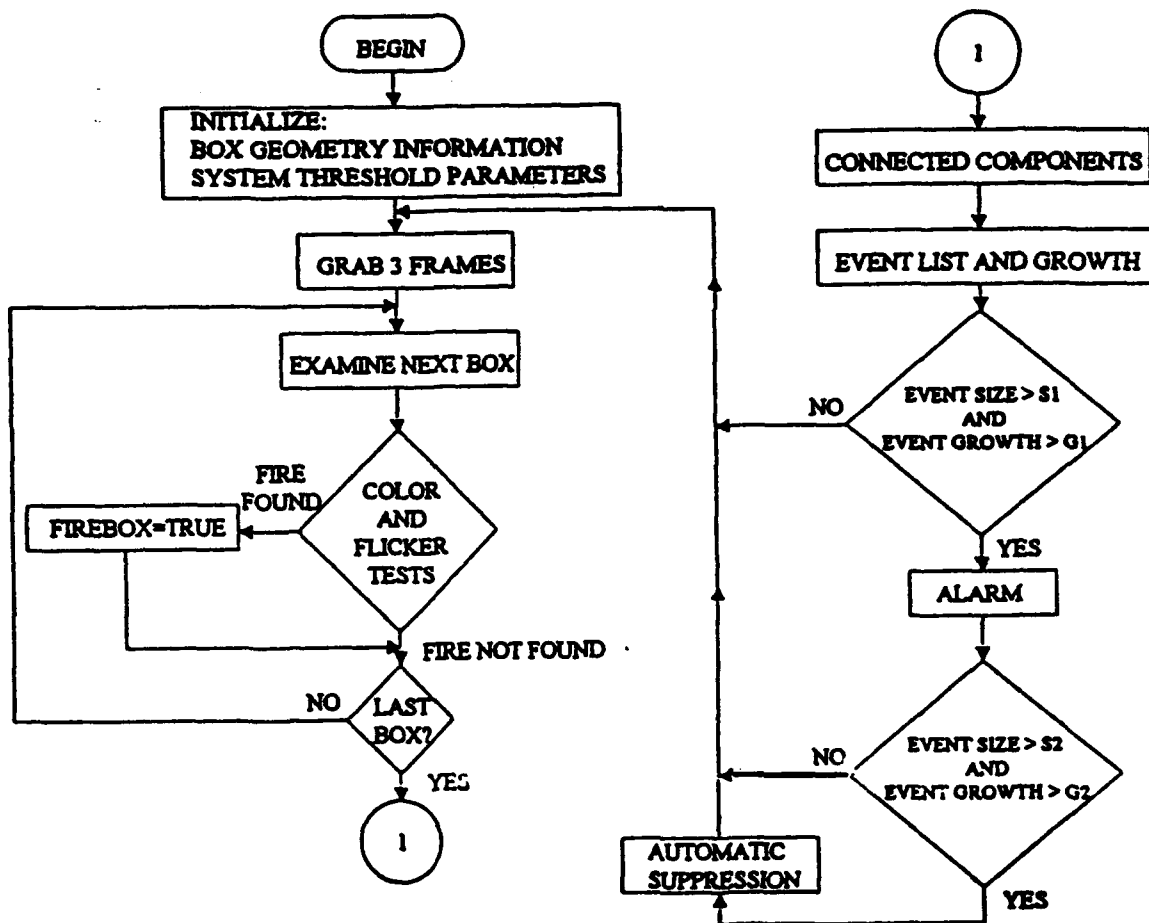


Figure 1. Fire Detection System Overview

b. Image Partitioning

The fire detection system gains efficiency by partitioning frames into variable size rectangular boxes. The size of these boxes is such that each rectangle corresponds to the same area in the scene. Typically, boxes near the top of the image will be smaller since they cover scene areas that are farther away and boxes near the bottom of the image will be bigger since they cover scene areas that are closer. Consequently, a fire of fixed area will fill the same number of boxes independent of its location. This partitioning scheme allows the system to be equally sensitive to a fixed size fire whether it is near or distant. Figure 2 shows an example of the partitioning of an image into boxes.

Three parameters are used to compute the size of a box at a particular image location (Figure 3). These parameters are the angle between the optical axis of the camera and the normal to the ground (θ_v), the angular field of view of the camera (θ_c) and the desired number of rows of boxes R . The first two parameters determine how box size should vary with image location. R determines the number of boxes to be created. As R is increased, the number of boxes increases and the boxes become smaller. Smaller boxes have the advantage of higher sensitivity but they also require additional computation.

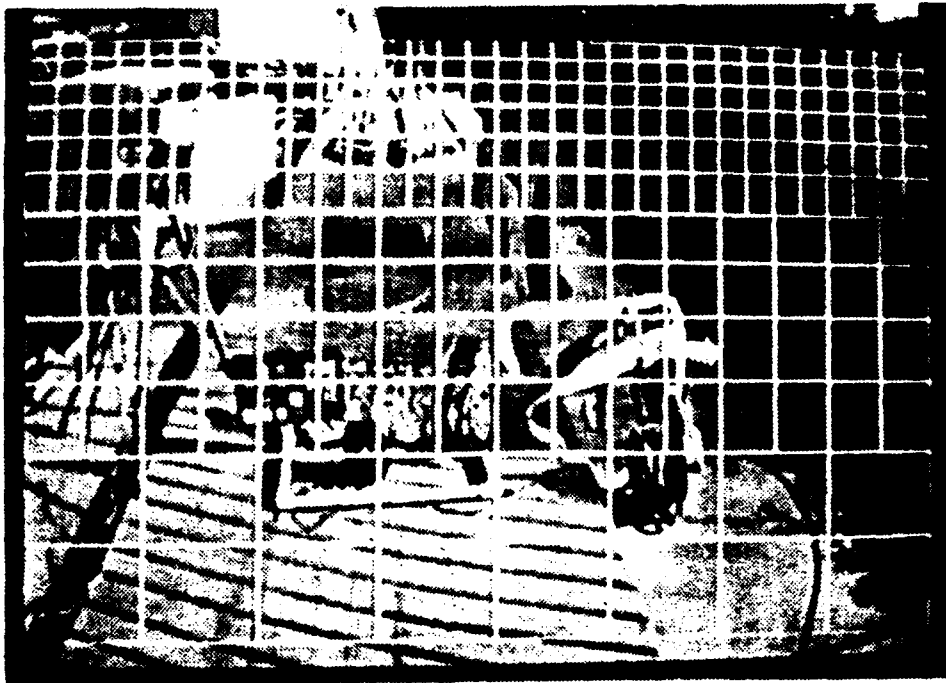


Figure 2. Example of Image Partitioning

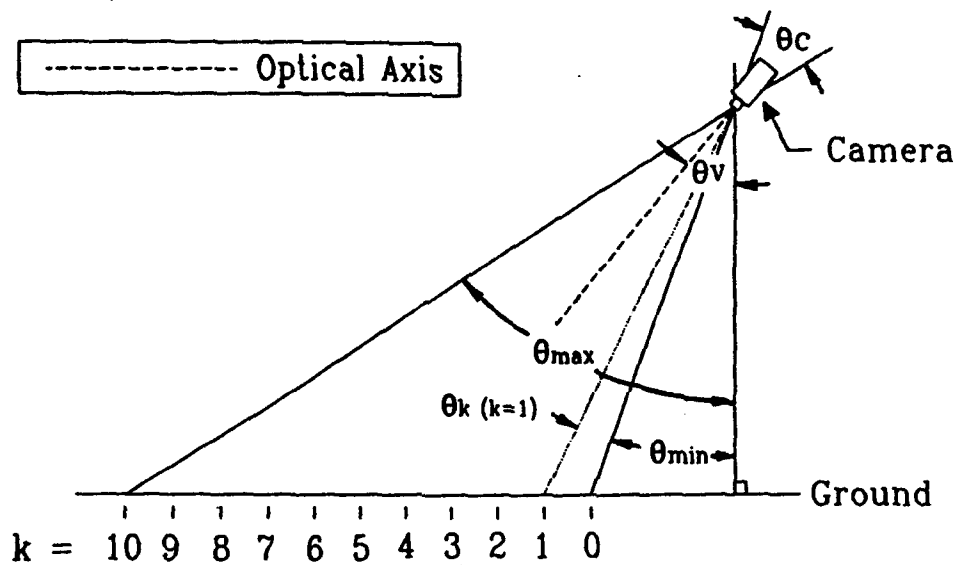


Figure 3. Imaging Geometry for $R=10$

Define

$$\theta_{min} = \theta_v - \frac{\theta_c}{2} \quad (8)$$

$$\theta_{max} = \theta_v + \frac{\theta_c}{2} \quad (9)$$

The y-coordinates y_1, y_2, \dots, y_R of the horizontal lines dividing the boxes are

$$y_k = \frac{\theta_k - \theta_{min}}{\theta_c} \cdot ysize \quad (10)$$

where ysize is the overall vertical size of the image and

$$\theta_k = \tan^{-1} \left(\frac{(R - k) \cdot \tan(\theta_{min}) + k \cdot \tan(\theta_{max})}{R} \right) \quad (11)$$

The horizontal box size for each row, $XSIZE_k$ is given by

$$xsize_k = [y_{(R+1)} - y_{(R)}] \cdot \frac{\tan\left(\frac{\theta_{(R+1)} + \theta_{(R)}}{2}\right)}{\tan\left(\frac{\theta_{k+1} + \theta_k}{2}\right)} \quad (12)$$

where \bar{R} denotes $R/2$. The x size for a box is set to be approximately the same as its ysize by using $y_{\bar{R}} - y_{(\bar{R}-1)}$, the ysize of the middle row, as a reference size for computing the xsize of other rows. The boxes are constructed so that a box will always have exactly one or two boxes above it. This is done by requiring that the x size of the boxes above is either the same or half the xsize of the boxes below. This requirement simplifies the connected components analysis described in C-1-d.

A box file contains all of the relevant geometric information about the boxes. During system operation, boxes are processed one at a time. Boxes that pass certain fire tests are processed further while boxes without fire characteristics are ignored. The use of this box structure allows the system to monitor efficiently the spatial structure of the scene without the overhead required to track individual pixels. Thus, fire characteristics can be detected using local pixel-based measures while fire events are tracked at a coarser resolution that is appropriate for a given application.

c. Color and Flicker Tests

The system acquires new color images every tenth of a second. For each new frame, several tests are applied to the pixels of each box to identify boxes exhibiting fire characteristics. The pixels of each box are examined using the RGB measurements obtained at that pixel for the current frame and previous two frames. Using a large amount of video data of burning jet fuel, the physical parameters of distributions of fire color and flicker were estimated for these events. Initially the multivariate normal density was used to describe the distribution of fire pixels in RGB space. The use of this density leads to a decision rule that classifies pixels inside an ellipsoid in color space as having fire color [Reference 10]. It was determined that this ellipsoid can be approximated by a rectangular volume with little loss in classification accuracy. The use of this approximation allows the system to achieve a significant speedup in pixel classification. Similar procedures can be used to estimate the characteristics of other kinds of fire events.

From the estimated color and flicker distributions, decision rules using estimated class boundaries are determined. These rules are based on classical pattern classification theory and are used to minimize the probability of classification error [Reference 10]. Since image irradiance is proportional to scene radiance independent of depth [Reference 11], a single set of

decision boundaries are valid over the entire image. On the other hand, since observed flicker is subject to greater spatial smoothing for fires at a greater distance due to an increased fire area projecting to a single pixel, the flicker decision boundary is adjusted according to the low pass characteristic of the sensor for patterns at greater distances.

Any pixel passing each of the physical tests is considered a fire pixel. If the ratio of fire pixels to total pixels in a box exceeds a pass threshold t_p , then the box is considered to contain fire. Note that as soon as a pixel fails any of the tests, examination of that pixel may be terminated greatly enhancing system efficiency.

During this project, several other tests, particularly those examining the representation and estimation of fire spatial spectral variation, were examined in terms of discriminatory power. While these tests are not used in the current system, preliminary results indicate that such tests can provide additional accuracy in fire identification. These fire characteristics provide an interesting area of study because of the large number of "within and between" color plane spatial correlations that exist in color images and the rich spatial structure of fires. The effect of the lowpass filtering of the optics and collection site sampling in the sensor must also be taken into account in this analysis because observed fire spatial structure is dependent upon the scale (i.e., distance) of the observation. Recent results in the scientific community on the use of vector Gaussian Markov random fields to model and estimate properties of color textures may provide important insights into the use of these parameters for fire detection [Reference 12]. Such methods will likely prove useful for many applications.

d. Connected Component Analysis

To determine the spatial extent of fire events that occupy more than one box, the system labels each connected set of fire boxes as a separate fire event. Identified events can be used to compute parameters such as the event size and growth rate. The connected component analysis executes very efficiently because of the typically small number of fire boxes that must be processed at any time step.

Using the image-partitioning method described in C-1-b, a box can have as many as nine neighboring boxes. Since the program scans through boxes from left to right and bottom to top, a box being examined can have at most four neighbors that have been previously examined: below left, below, below right, and left. In cases where the boxes below have twice the xsize of the box currently under examination, the below right and below neighbors or the below left and below neighbors might be the same box.

With only the modification that a box might have nine neighbors instead of eight, a standard connected-components algorithm [Reference 13] is applied to the fire boxes to find connected fire events. If events identified at consecutive time steps share at least one fire box, the events are assumed to be the same and are assigned the same label. If two fire events merge, the event number previously associated with the largest of the events will become the label for the merged event.

e. Estimating Size and Growth

Once fire events have been described in terms of their component boxes, the system computes the size of each event in the scene and its corresponding growth rate. Using a projection model for the imaging system, each pixel in the image corresponds to a certain area in the scene. For simplicity, the approximation is used that each of the pixels in a single grid box corresponds to the same scene area and this area is associated with the box.

The scene area corresponding to a fire box is computed as the number of fire pixels multiplied by the scene area per pixel for the box. The scene area of a fire event is the sum of the scene areas for the fire boxes corresponding to the event. These areas are straightforward to compute using the event representation described in C-1-d.

The average growth rate for an event is computed as the event size divided by its duration. Instantaneous growth rate is defined as the event growth over the previous tenth of a second divided by 0.1 second. Growth rates are typically monitored in units of square feet per second. When a fire event exceeds a predetermined size and growth rate, specified actions are taken. These actions include the sounding of an alarm and the automatic release of suppressant to control the fire event.

f. Video Testing

In this section, algorithm performance is demonstrated on video sequences containing jet fuel fires and false alarms. This testing was carried out using a Truevision Targa frame grabber in conjunction with PC hardware. Figures 4-7 show the progression over a few seconds of a jet fuel fire in the presence of false alarm stimuli. We demonstrate the output produced by our system for this sequence. Frames acquired before and after each displayed frame also contribute to the generated output associated with that frame as explained in C-1-c.

In Figure 4, the fire has not yet started. Figure 8 labels the corresponding pixels that satisfy the fire color

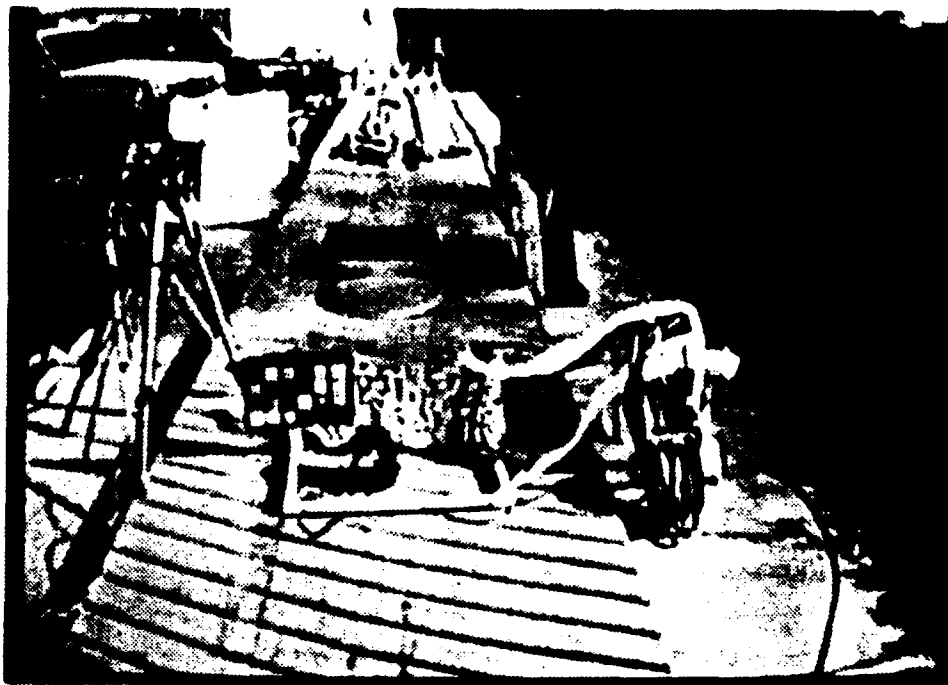


Figure 4. Scene with No Fire

condition. No boxes at this time were determined to contain fire.

In figure 5, the fire has started to grow. Figure 9 labels the pixels that satisfy the fire color condition and figure 10 displays the boxes that are determined to contain fire based on color and flicker tests and the pass threshold. From these boxes, an event description is generated that describes the fire location, size, and growth rate.

The fire shows further growth in Figure 6. Figure 11 indicates pixels which satisfy the fire color condition and figure 12 displays boxes that are determined to contain fire. The system continues to monitor location, size, and growth.

Figures 13-14 show system output as the fire continues to grow (Figure 7). On this sequence as well as on a large amount of additional test data the system has proven to be very reliable in identifying fire events while maintaining immunity to false alarms. In a full scale development mode, further testing will be required to refine the parameters of the system and to integrate additional algorithms. Mechanisms for optimizing the system for specific classes of applications will be studied. In addition, a detailed systematic test program will allow accurate quantification of system performance for diverse ranges of input.

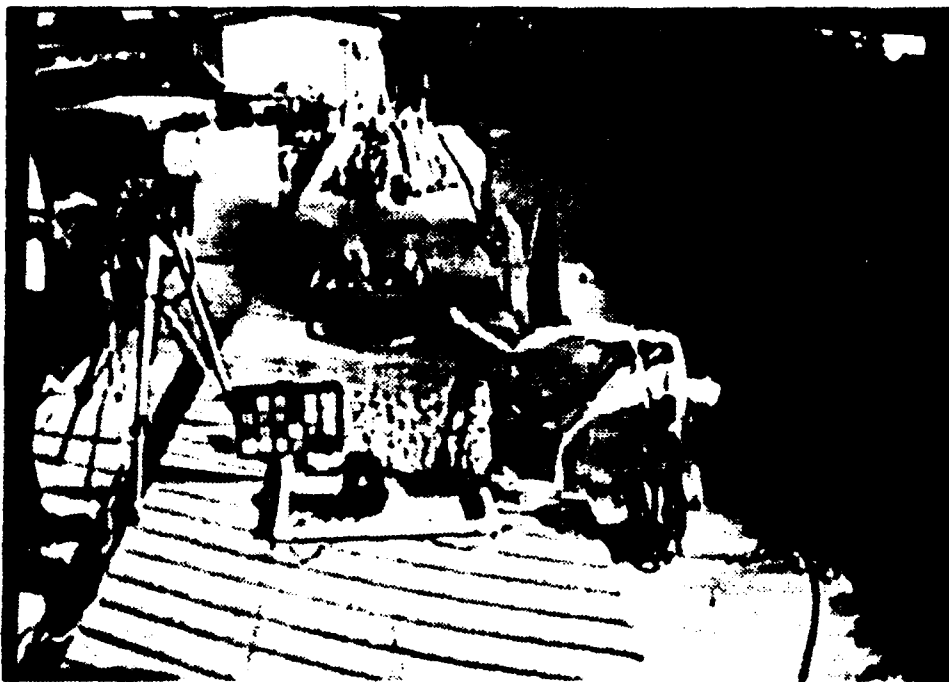


Figure 5. Scene with Small Fire

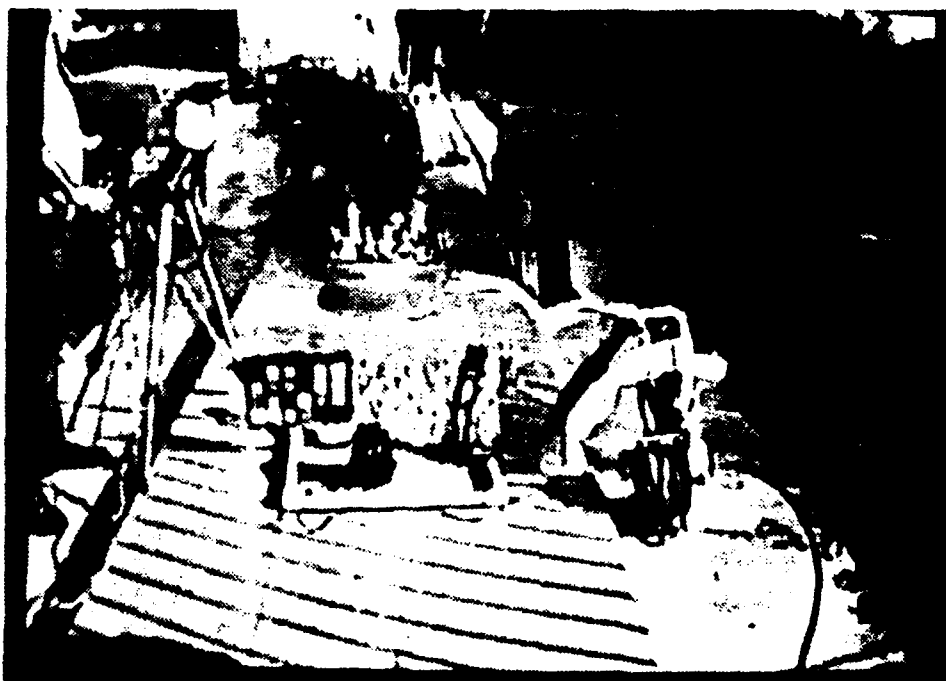


Figure 6. Scene with Growing Fire

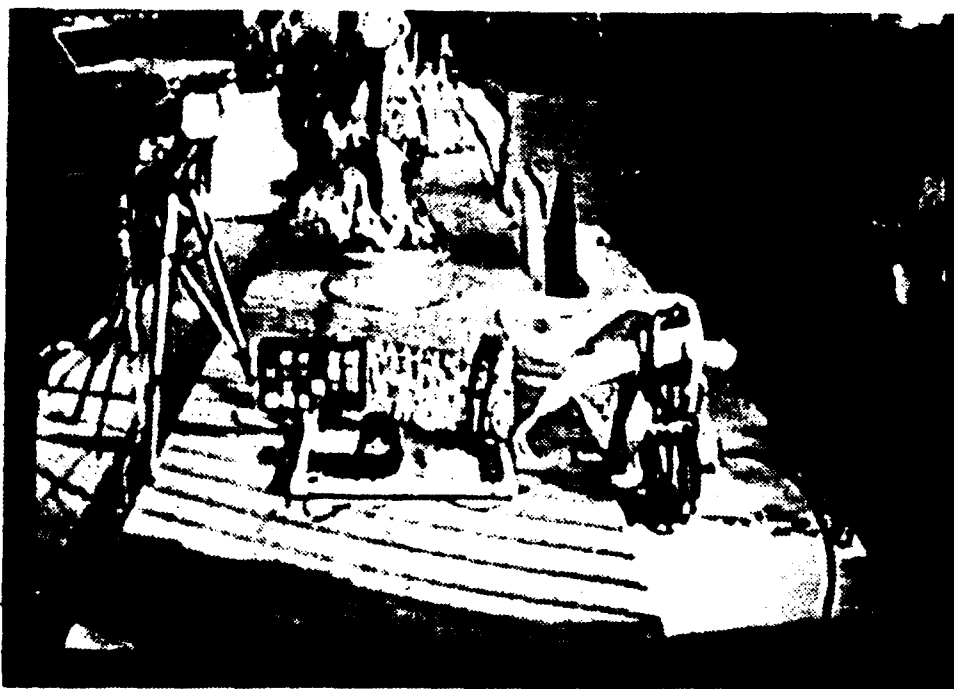


Figure 7. Continuation of Growing Fire

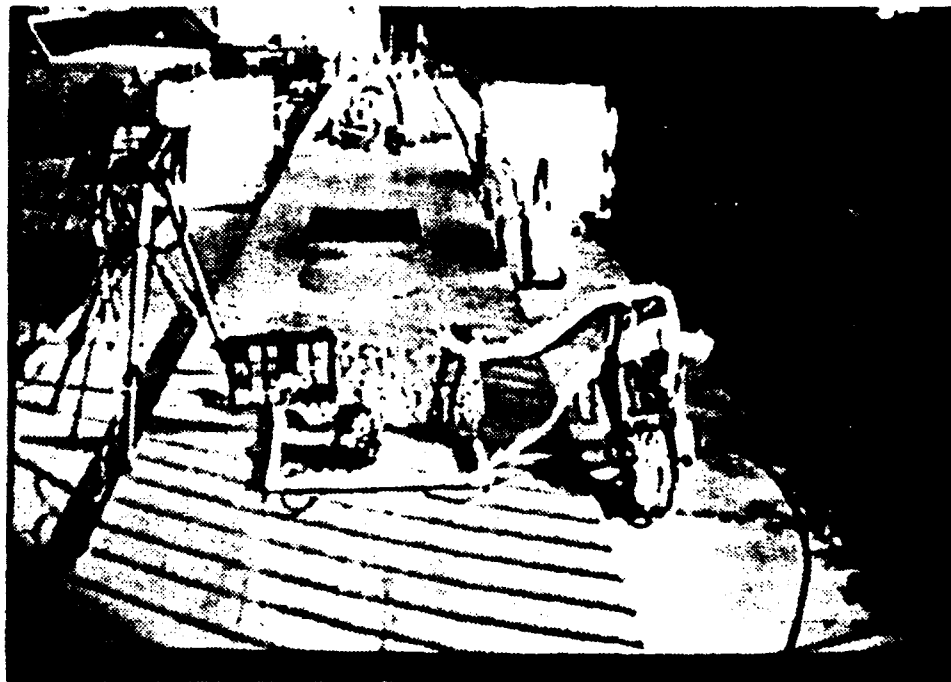


Figure 8. Pixels Passing Color Test in Figure 5

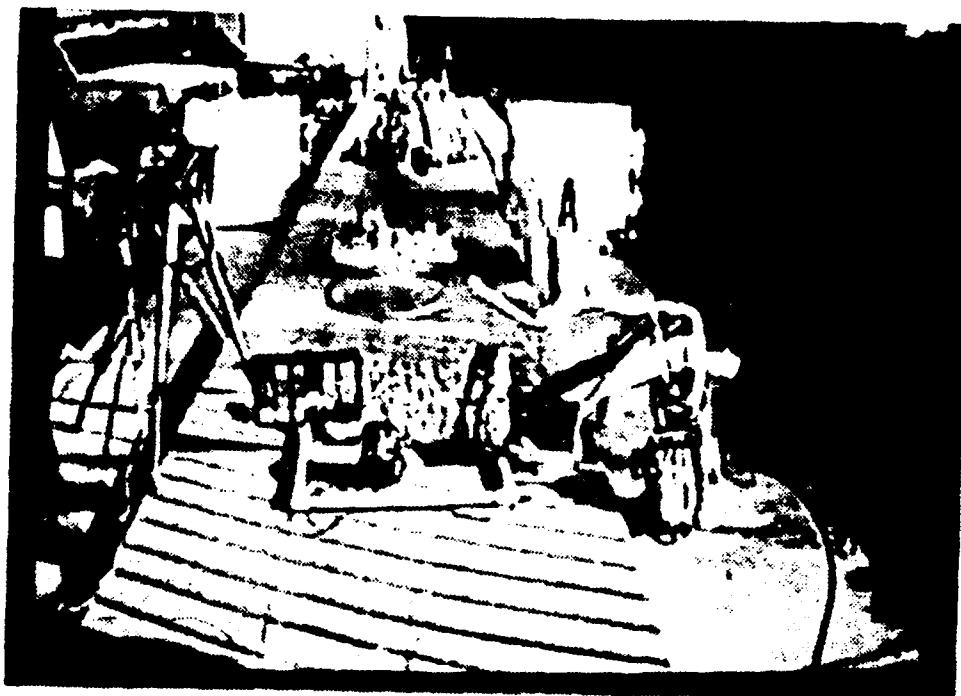


Figure 9. Pixels Passing Color Test in Figure 6

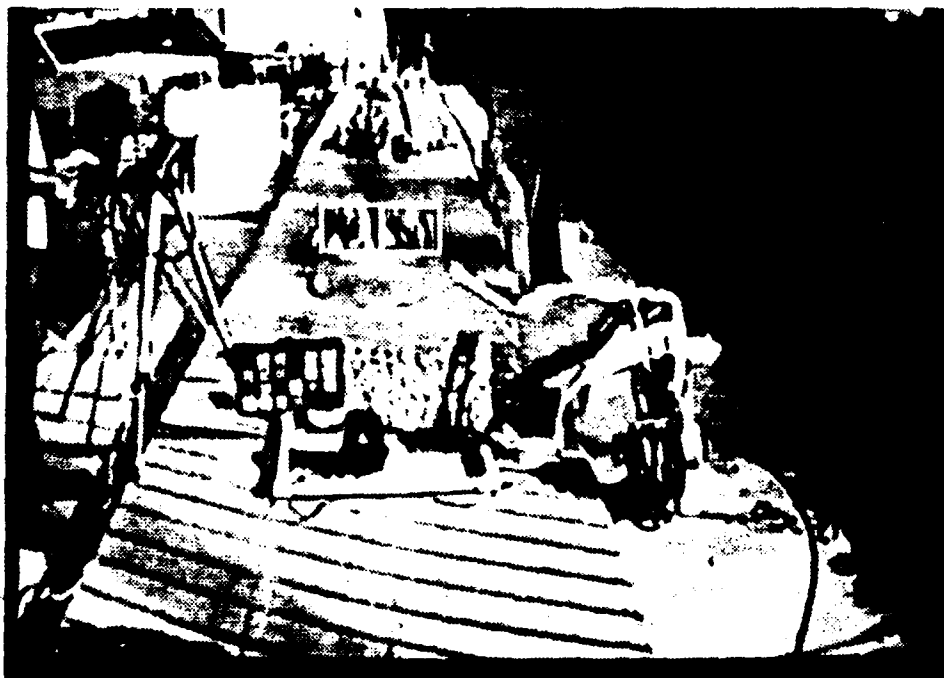


Figure 10. Identified Fire Boxes for Figure 6

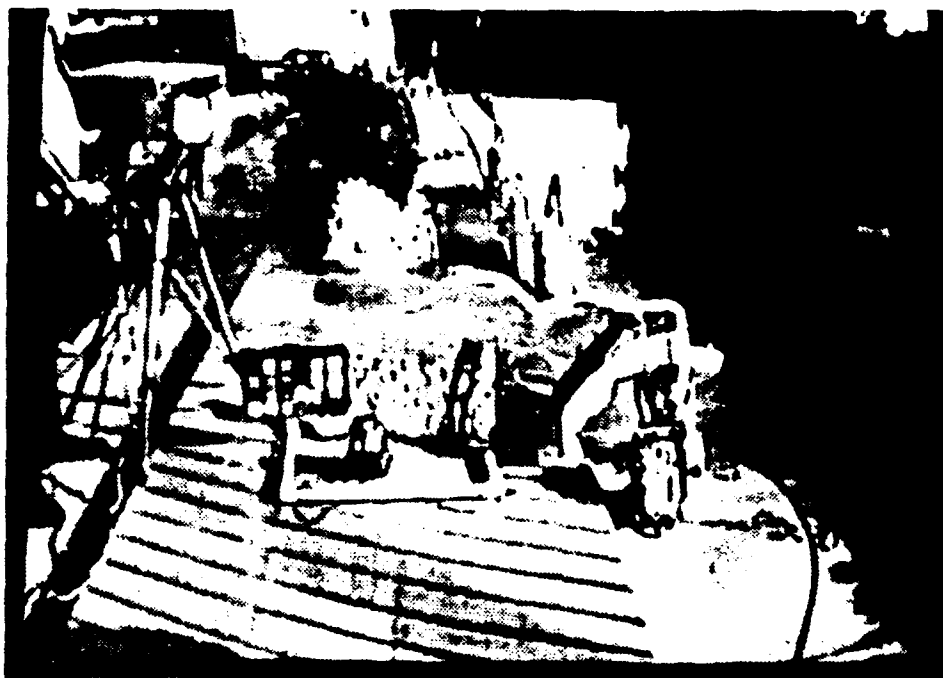


Figure 11. Event Description for Figure 6

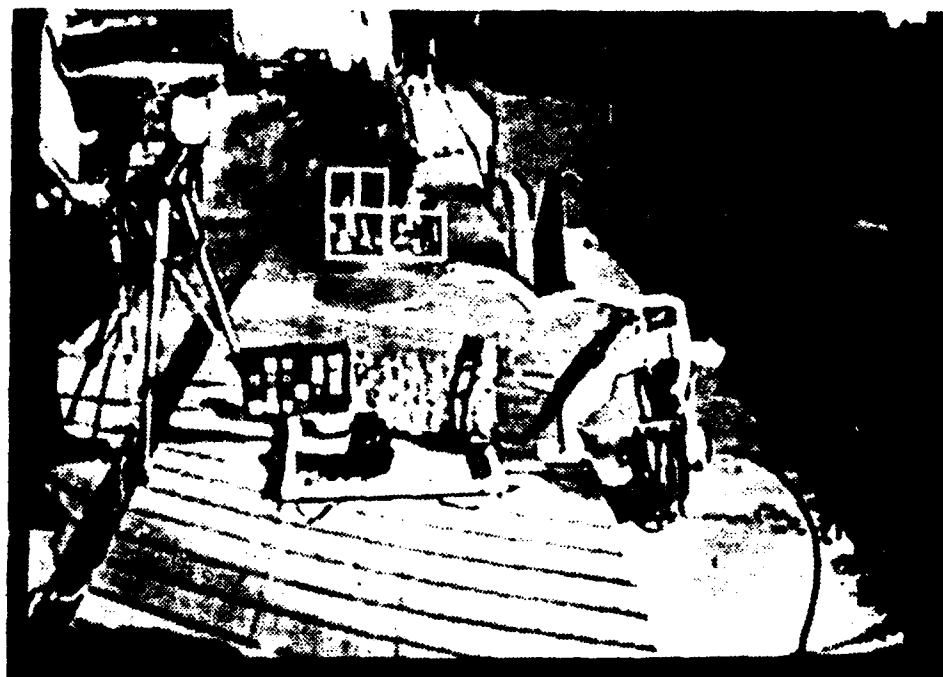


Figure 12. Pixels Passing Color Test in Figure 7

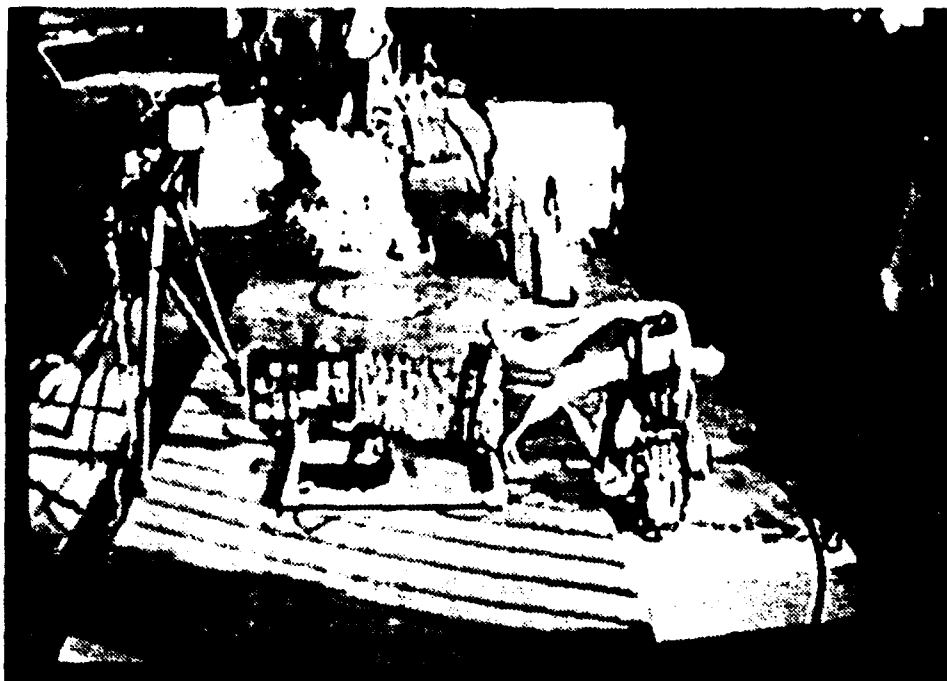


Figure 13. Identified Fire Boxes for Figure 7

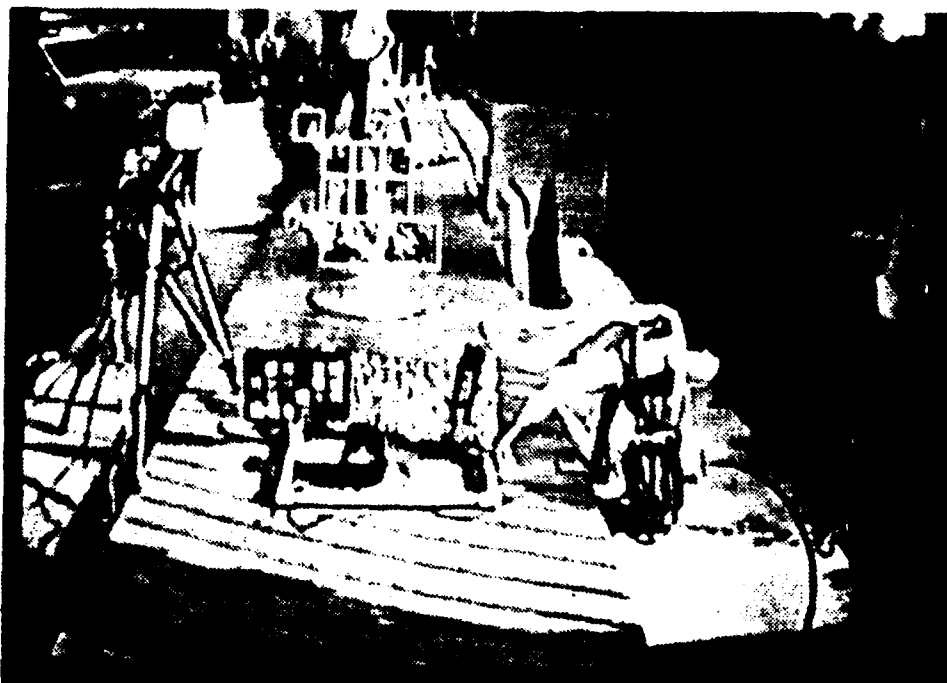


Figure 14. Event Description for Figure 7

SECTION IV

MACHINE VISION FIRE DETECTION SYSTEM HARDWARE DESCRIPTION (MVFDS HARDWARE MANUAL)

A. OVERVIEW

This section describes the hardware configuration and operation of the MVFDS prototype microcomputer-based systems, designated herein as MVFDS SYS.IGB-n. Two types of systems described are designated by the "-n" suffix, where a "-S" indicates a single camera system and a "-D" indicates a dual camera system. In the following descriptions the MVFDS SYS.IGB-n will be referred to as MVFDS.

The MVFDS is designed to reliably detect and discriminate true fires from nonfire objects and phenomena, calculate the growth and size of the fire and then produce alarms and suppressor activation signals when the fire reaches a critical size/threat threshold. The prime application of MVFDS developed in this specific project is detection and suppression of aircraft fuel fires in operational aircraft hangar environments. Other applications, including hot-pit refueling fire protection, crash rescue vehicle turret control, aircraft dry bay, engine bay, and cargo bay protection, and others are being developed, or will soon be developed, under separate government sponsored programs.

Present state-of-the-art ultraviolet (UV), infrared (IR) and combined UV/IR discrete fire detectors alone are susceptible to false activation from a variety of benign UV and IR emission sources that can occur singly or in spatially separated combinations within the field-of-view of the detector (whether inside or near an aircraft hangar). The MVFDS color video imaging detector and intelligent microcomputer processing software overcome this problem.

The MVFDS identifies the visual physical characteristics of fires while discriminating the fires from all other radiating sources and combinations of sources that may cause false activation. The MVFDS selectively identifies fires by computer analysis of the visual scene in the field-of-view of the color video camera. It identifies the true fires based on the fire visual spectral characteristic colors ranging from yellow, orange, red, and magenta to violets. It subsequently analyses the spectral, intensity, and spatial features, including spectral flicker, to discriminate the fire, and then determines the fire distance, size and growth rate. When the MVFDS detects the beginning of a small fire it outputs an alarm signal, continues monitoring the fire as it grows to a predetermined threshold size, then the MVFDS outputs a fire suppressor activation signal.

B. SYSTEM CONFIGURATION

The MVFDS hardware consists of single- or dual-color video cameras, a real time video image digitizer and processor (simply called a Frame Grabber [FG]), a host microcomputer, an Input/Output(I/O) alarm, and suppressor output interfaces. Refer to the MVFDS block diagram in Figure 15 for a detailed overview of MVFDS prototype system hardware and its components which are discussed below. Figures 16 and 17 show hardware components.

Two types of MVFDSs have been designed, a single-camera and a dual-camera system. Standard video cameras that use a single detector with three color filters Red, Green, and Blue (RGB) are used as the video imaging sensor. The cameras acquire 30 video frames per second and output RGB and/or NTSC RS170 analog signals. The MVFDS presently uses the camera NTSC RS170 signal to convert the video frames into digital computer data for processing. The video frame data is acquired upon command, digitized and transferred into the FG video memory. Up to four frames of digital image data are stored in video memory on the FG. The FG has a high-speed graphics microprocessor to process the image data at

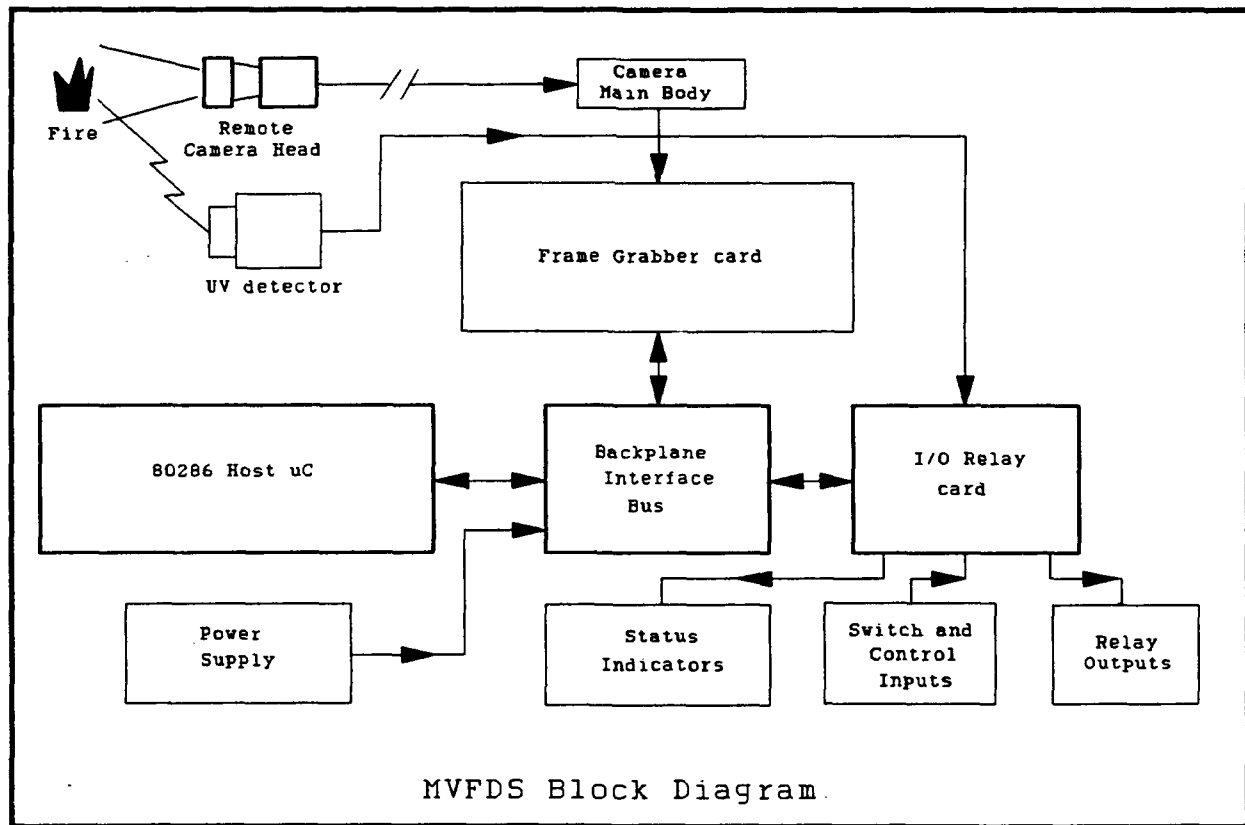


Figure 15. MVFDS Block Diagram

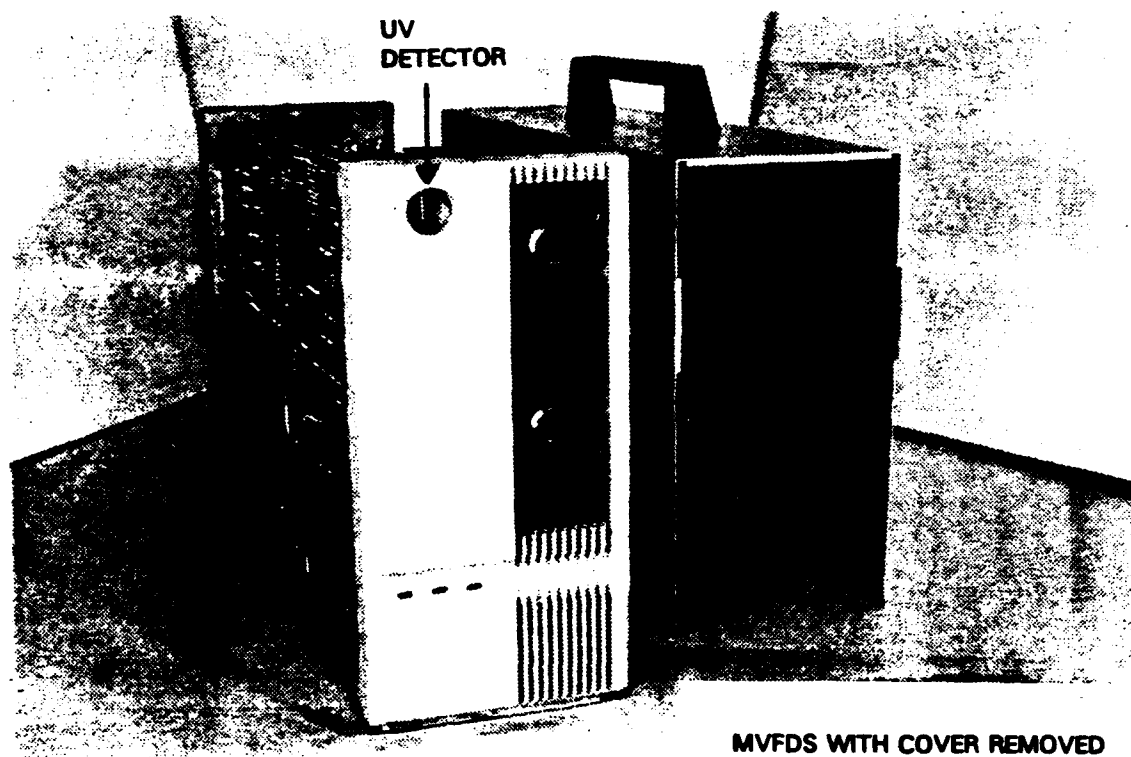


Figure 16. Camera and MVFDS with Cover Removed

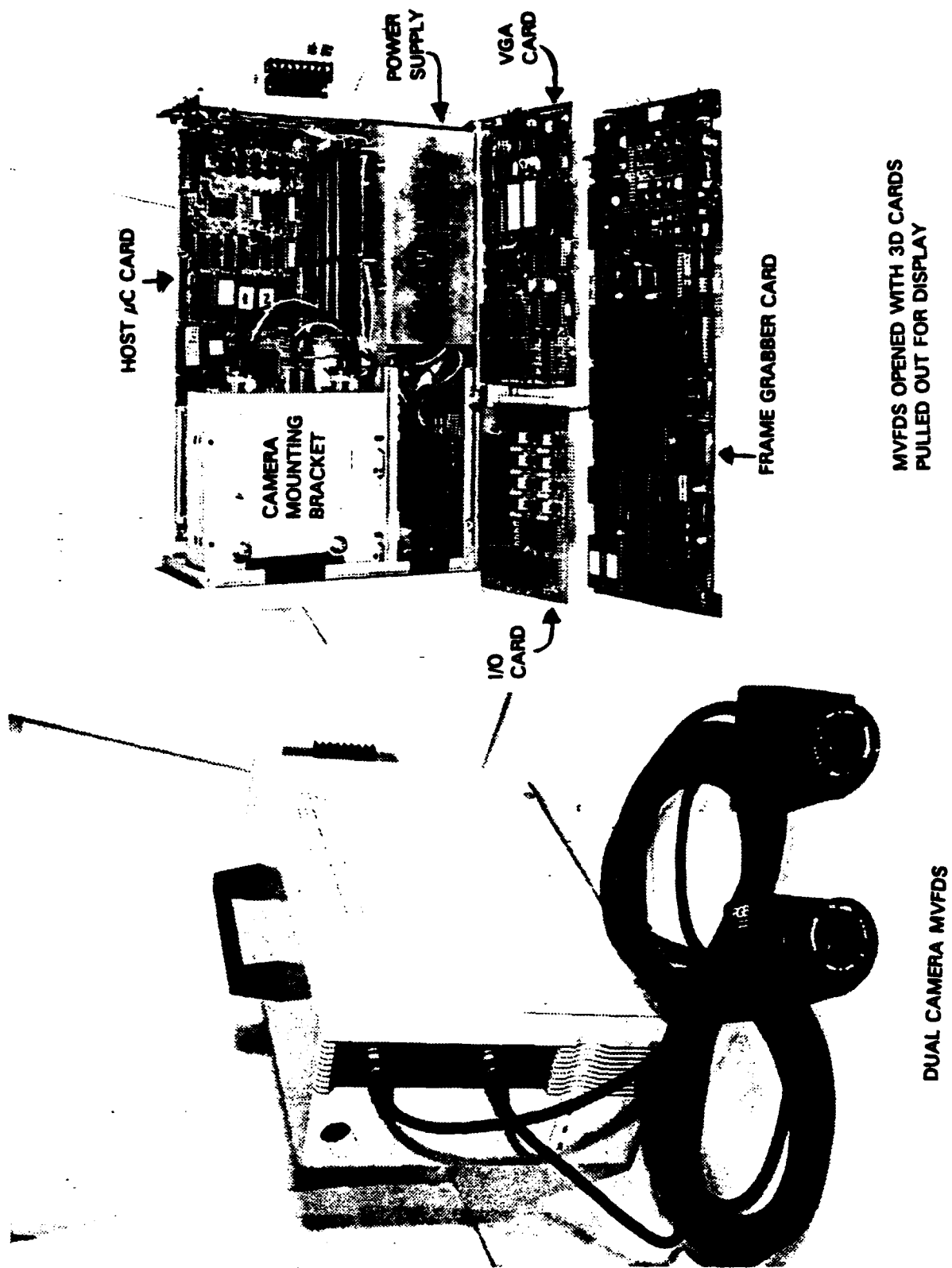


Figure 17. Dual Camera MVFDS and 3D Cards Displayed

real time speeds. It processes the spatial and spectral information obtained from fire emissions with the color video cameras to effectively discriminate true fires from benign nonfire emission sources. The FG card is interfaced to an 80286 host microcomputer card via the expansion connector slot on the microcomputer chassis backplane. The 80286 AT host microcomputer performs all the system level software functions such as initialization, built in test, program file operations, and I/O interfacing on itself and the FG card.

The following technical description delineates the MVFDS functions, based on currently available commercial hardware, required to implement the prototype MVFDS. The video cameras, FG card, I/O card and 80286 AT microcomputer hardware are described plus the essential operating software required to implement the computerized machine vision fire detection technology. The functional prototype MVFDS system hardware components utilized are currently available state-of-the-art microcomputer hardware and software packages that are detailed at the end of this description.

1. Color CCD Video Cameras and UV Detector

- a. Color CCD Camera

The primary detector used in the system is a standard solid state Charge Coupled Device (CCD) color video camera that produces three primary color analog signal outputs in RGB and NTSC RS170 formats. The RGB or NTSC RS170 signals can be recombined in a color display monitor to recreate the multitude of original colors in the imaged scene. The CCD imaging device consists of a rectangular solid state light detector array composed of individual picture elements called pixels. Each pixel has a defined horizontal (HORZ) column and vertical (VERT) row coordinate (address) in the array by which it can be accessed. The color image focused upon the detector surface is separated into three primary colors red, green and blue (RGB) by vertical RGB color stripe filters placed over each set of three horizontally adjacent pixels. The impinging light level/color information acquired by all the array pixels is scanned sequentially by the camera internal electronics to produce serial video analog voltage output signals for each of the three primary colors, RGB. Presently available CCD color cameras have very good low light level resolution, contrast and wide dynamic range which is necessary in the highly variable hanger lighting conditions. The CCD camera's high performance and very small size are very important factors for this application. Refer to Figure 16 for photo of camera.

The CCD cameras used have a horizontal and vertical pixel array resolution of 512 x 486 for a total of 248,832 pixels in each frame. The CCD array has a rectangular horizontal-to-vertical aspect ratio of 4:3. The MVFDS cameras used in this project are fitted with 60 degree angle field-of-view (FOV) high quality lenses

which result in a horizontal FOV of 60 degrees and a vertical FOV of 45 degrees. These angles are important in distance calculations discussed further on. A 60 degree FOV lens with manual iris was chosen for the functional prototype in order to resolve small fires at distances of 100 feet and more. A 90 degree FOV lens should be able to resolve sufficient number of pixels in the image to provide discrimination of a 2-foot x 2-foot fire at about 100 feet. It is also important to use high quality lenses because there are variations in the transmissivity of RGB.

In Figure 15 the image of a fire, represented by the triangle, is focused by the camera lens upon the CCD imaging device pixel array which translates the light level at each pixel into an analog voltage. The camera electronics provides precision clock controlled timing and sweep drive for HORZ and VERT scanning the CCD pixel array. This produces a serial stream of pixel data for each of the three colors. Precise horizontal and vertical synchronization (HORZ SYNC) and (VERT SYNC) are output to define the format of each complete frame. Each complete video frame is output at 30 frames per second (in 1/30 second). Each frame is composed of a sequence of two interlaced fields captured at 1/60 second apart. The MVFDS uses the complete interlaced frame for processing.

In an aircraft hangar/shelter application 30 frames per second CCD speed is sufficient to adequately identify and discriminate a fire event as small as 2 feet x 2 feet at 100 feet distance in less than 1 second. However, in other applications, such as military aircraft dry bays and Army munitions production plants, faster speeds are required in order to identify the event within about 10 milliseconds.

The camera electronics contained in the main camera body provide digital control of the CCD exposure integration time from as long as 1/60 second to as short as 1/20,000 second. The effect of changing integration time is equivalent to changing the manual lens "f" stop to accommodate varying light levels in a scene. It also provides stop action or "freeze" action for the rapidly changing objects in a scene. The integration time is independent of the frame transfer rate which is always at 1/30 second. Therefore, for example, a frame captured at 1/1000 second is transferred out of the camera in 1/30 second.

The MVFDS acquires three frames 0.1 second apart for analysis at an integration time of 1/1000 second with the manual lens iris set at f5.6. These settings have been optimized to acquire the intense fire images without saturating the CCD imager and provide clear non-smeared stop action of the rapid-fire flicker characteristics for analysis. In situations where a display monitor is used with the MVFDS these settings greatly reduce the overall brightness of the scene making all other nonfire objects nearly invisible under subdued interior lighting situations. Therefore during the balance of the analysis period a fourth frame is

captured at an integration time of 1/60 second to display the live scene at higher light levels.

Refer to Figure 18 for an illustration of the standard NTSC interlaced scanning process. The VERT SYNC pulse signals the beginning of a new frame scanning the first of two interlaced video fields starting at the top left corner of the image captured on the CCD pixel array. The HORZ SYNC pulse initiates the scan from the right across the top row of pixels and when it reaches the right side another HORZ SYNC pulse is produced which skips a row and starts the next scan line. This is repeated, each time incrementing to the next line below until it reaches the bottom of the frame at which time another VERT SYNC pulse returns the scan to the top middle of the screen to begin the next video field which is interlaced between the lines of the first field. Upon completion of scanning the two fields another VERT SYNC pulse starts a whole new frame.

The color camera produces color video using the industry standard three primary color analog outputs, red, green, blue (RGB). It also outputs horizontal and vertical synchronization (SYNC) signals which either output separately or combined in the

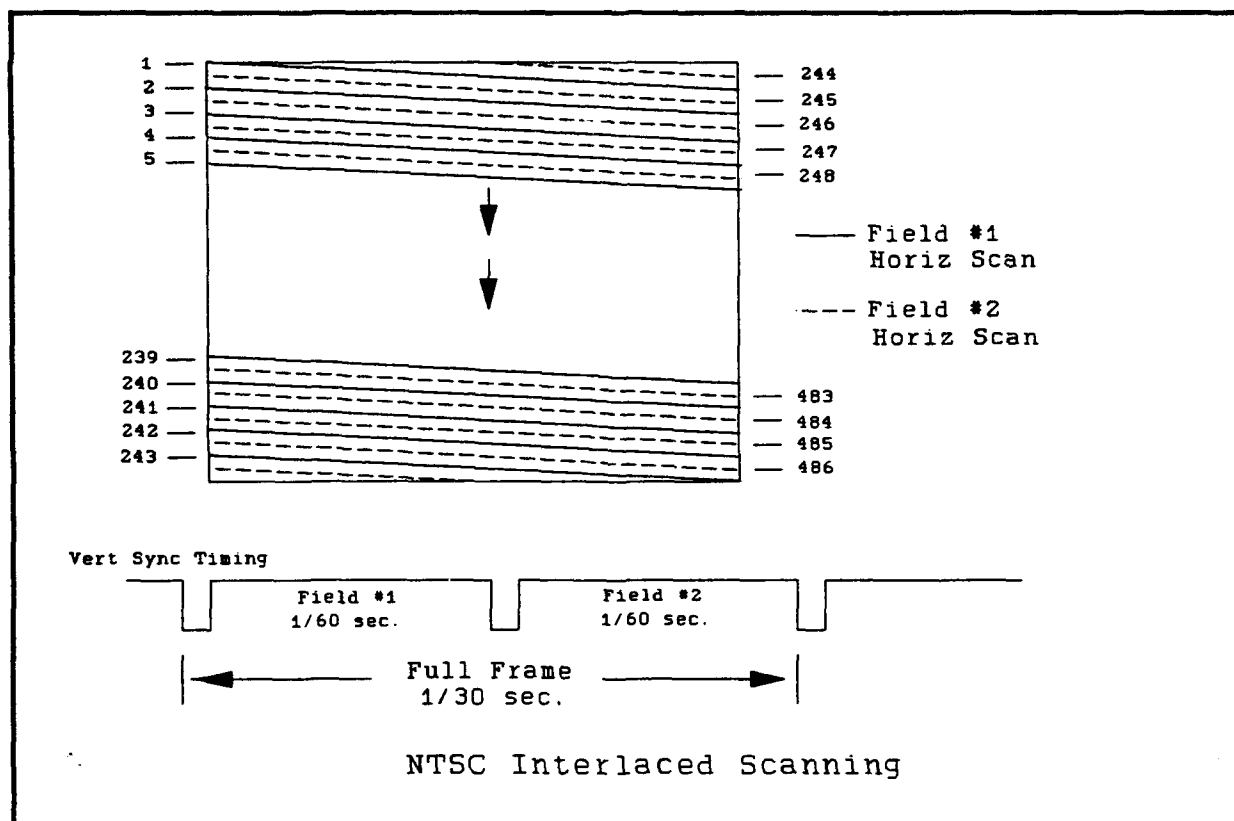


Figure 18. NTSC Interlaced Scanning

industry standard NTSC format color video output signal. The three primary color RGB levels when recombined in triad combinations on a color monitor can recreate all the colors captured by the camera.

b. UV Detector

One of the features of the MVFDS is that it can incorporate the detection mode of other fire detectors into its "AND" logic, if desired. For example, if UV detectors are already installed in a shelter, but they are having false alarm problems, an MVFDS could be installed to greatly increase reliability against such false alarms. The "fire present" signal from the UV detector could result from any nonfire source of UV of spectral irradiance in the 190nm - 260nm band which is greater than or equal to the threshold fire size that the UV detector is designed to detect. Upon UV detector alarm, the MVFDS would be required to identify the fire before the suppression system was activated.

The functional MVFDS unit has been supplied with a UV detector to provide testing of this concept. The selected UV detector is a miniature (1/4 inch diameter x 1 inch long) bipolar gas discharge tube that is packaged with a high voltage supply and digital signal conditioning circuit. The tube quartz envelope, gas pressure, gas mixture and photocathode parameters are designed to detect UV from flame sources in the narrow range of 180 to 260 nanometers. The sensitivity is set very high to detect a flame as small as that from a cigarette lighter at 5 meters. The detection threshold can be adjusted to count rates from 3 to 20/second, which corresponds to a range of irradiance values.

The UV detector is not required as an "AND" signal, but it could, under certain conditions, be considered to add additional reliability to the fire detection/discrimination mode. The discrete UV detector lacks specific spatial information of distance, size and growth when used alone. However, when used in conjunction with the color video camera it provides confirmation a fire is present when the MVFDS interprets the camera information. The UV detector output is input to the MVFDS via the I/O card. The signal can be logically "ANDed" or "NOT ANDed" using a switch on the back panel to control the suppressor activation signal.

2. Video Frame Grabber

The Frame Grabber (FG) is the key interface device to convert the real time color video camera analog RGB or RS170 output signals into digital video image data. At present the RS 170 signal is used to take advantage of the FG card multiple color camera multiplexing input feature for the dual camera MVFDS. The FG card can capture up to four multiple video frames into high speed video memory on the card for processing. The host microcomputer can instruct the FG card to capture video frames output from the video camera, digitize the data and store the data for the whole frame in

the high speed video memory. The digitally stored frame image data is then accessible to the FG graphics microcomputer for processing. The FG graphics microcomputer can capture frames at any rate up to the maximum 30 frames per second. The MVFDS captures frames at 0.1 second apart to provide good separation and discrimination of fire flicker characteristics from passive spectrally pure fire colored objects such as red lights, red clothing, flags and painted objects. Refer to Figure 19 block diagram and Figure 17 for photo of FG card.

The RGB, HORZ SYNC and VERT SYNC signals from the camera are input to the FG card. The SYNC signals coordinate the systematic capture of pixel array information and ordered storing of the data in the video frame buffer memory. The three RGB analog voltage inputs are digitized with a very high speed analog-to-digital (A/D) flash converters and the digital values for the three colors placed into the correct video frame buffer memory address for each pixel. The microcomputer can access each pixel address to process the information. As each pixel is obtained it is compared with the fire threshold levels for the fire visible color

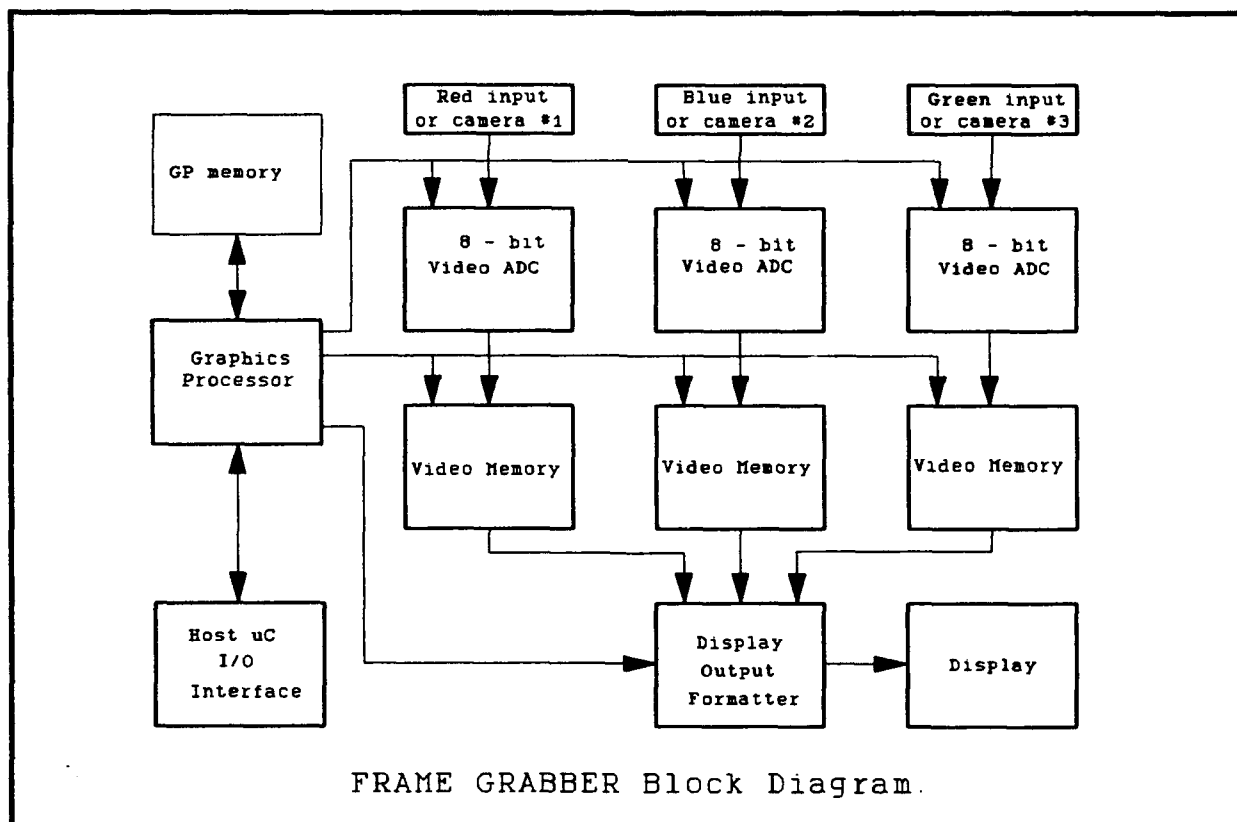


Figure 19. Frame Grabber Block Diagram

spectrum stored in a lookup table input to the system at installation calibration. During the scan of each frame a running count of the pixels exceeding the threshold are accumulated for a frame total. The total is stored in memory for comparison with subsequent frames to monitor the fire physical size, intensity, growth rate and characteristic flicker frequency attributes.

3. Host Microcomputer Board

The MVFDS main control host microprocessor is a 80286 AT microcomputer operating at 25Mhz which has 4Mbytes of RAM memory, 1.44Mbyte ROM disk drive, watchdog timer, printer port and clock/calendar. The host microcomputer performs all the initialization, program operation, communication between cards and all other supervisory functions. During the normal fire detection program cycle the host microcomputer monitors the fire size and growth data output by the FG card and outputs the correct response through the I/O card.

4. Real-Time Software

The computer hardware requires software programs to operate the host microcomputer, the FG card and I/O control the system. The host microcomputer requires a primary operating software that initiates operation of the host microcomputer using a Basic Input Output System (BIOS) low level machine language permanently stored in a Read Only Memory (ROM) integrated circuit. The BIOS software first performs host microcomputer initialization and self test which enables the host to start the boot up from the 1.4Mbyte ROM disk. The second boot operation initializes the FG card graphics processor and I/O card. The third boot operation progresses to a self testing procedure and begins running the Fire Detection Program (FDP) with periodic self test procedures run to verify operational status. The majority of the high level FDP is programmed and compiled in "C" language except for speed sensitive subroutines that are compiled on to the FG card in the high speed graphics processor machine language.

5. System Enclosure, Power Supply, and Connectors

As shown in Figures 16 and 17, the whole system, except the remote camera heads, is packaged in a single enclosure partially sealed from the environment with connectors/cables provided for power and I/Os. The I/O includes connectors on the front for single or dual camera heads to be mounted strategically in the hangar environment. On the rear panel a connector provides isolated relay contacts for the normal operation indicator signal, fire alarm signal and the suppressor activation signal. The enclosure contains a well regulated low voltage power supply required for all system components: the host microcomputer, frame grabber board, camera electronics and I/O card.

6. I/O Card

The input and output (I/O) activity of the microcomputer operating under control of the FDP uses the I/O card to digitize the UV detector input and send the data to the microcomputer for action. Fire alarm and suppressor activation decisions from the microcomputer drive on-board action indicators and provide relay isolated outputs to interface with the external alarms and suppressor drivers.

C. FUNCTIONAL HARDWARE MANUAL

1. External Connectors and Controls

a. Camera Connectors

As shown in Figures 16, 17 and 20, the MVFDS enclosure has either a single or a dual set of camera connectors on the front panel. The connectors are marked with the serial number of the matching remote camera head. It is necessary to connect the correct remote camera head to the matching internal camera control electronics to maintain the factory calibration and settings. The

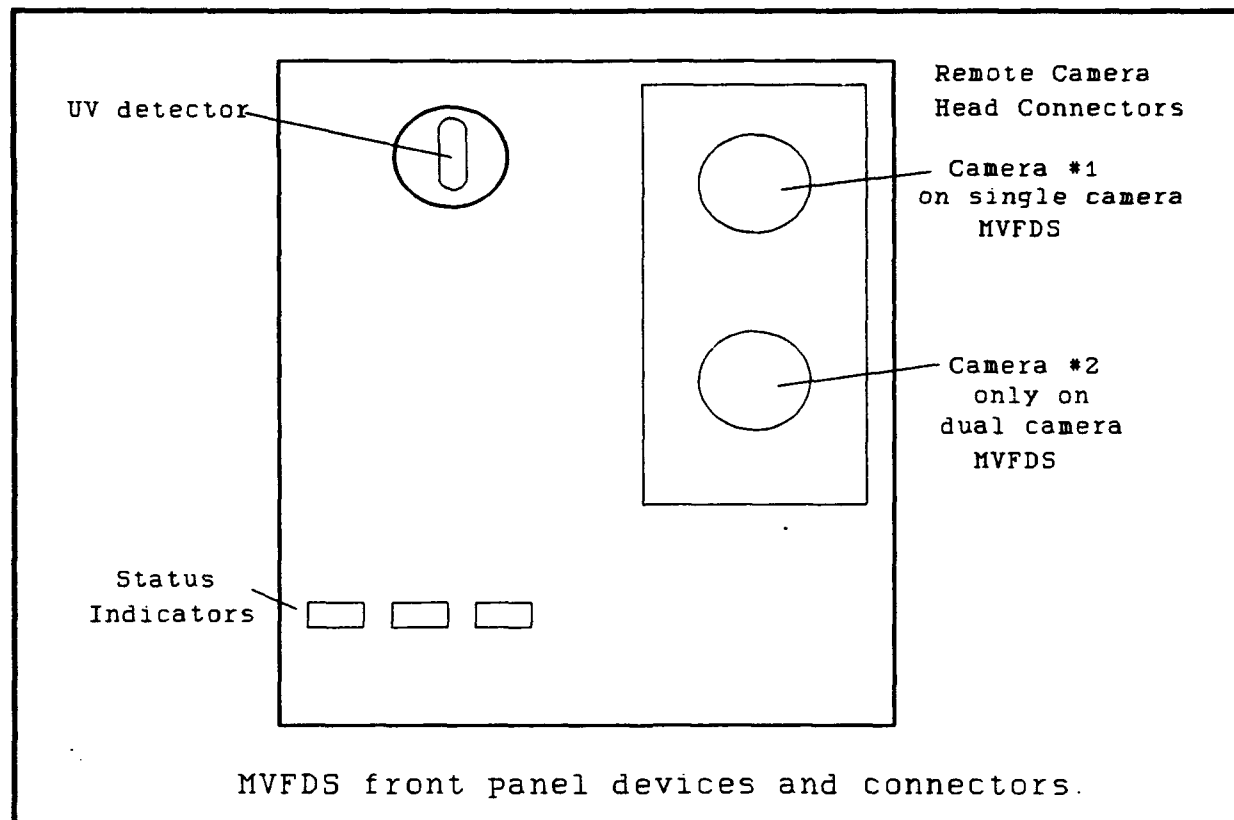


Figure 20. MVFDS Front Panel Devices and Connectors

remote camera heads are factory equipped with 5 meter cables.

b. UV Detector

The UV detector tube is mounted inside the opening at the top left corner of the front panel (see Figure 20). The UV detector tube is directly exposed to the environment without any cover plate (in an operational unit a glass cover plate would be provided if a UV detector was desired). Avoid touching the tube with fingers since an oily finger print on the tube may cause attenuation of the UV entering the detector. If the tube appears to be soiled with smoke or soot the tube must be cleaned with alcohol using a cotton swab and allowed to dry thoroughly before reapplying power to the MVFDS.

The output of the UV detector electronics is displayed as pulses or a steady "on" state of a yellow LED located at the top right side of the rear panel. The UV output is also read into the host microcomputer via one of the optically isolated inputs on the I/O card. A switch on the top left corner of the enclosure back panel, labeled AND or NOT AND, enables or disables the UV detector signal to be logically combined with the MVFDS suppressor dump output.

c. Operation Status Indicators (See Figure 21)

Operating status LED indicators are located in a row across the top of the enclosure along with two control switches.

(1) DET MODE Indicator

The green LED cycling on and off indicates normal operating status when no fire is detected. Each cycle indicates three frames have been grabbed at 0.1 second apart and subsequently analyzed to search out fires.

(2) DET FIRE Indicator

The yellow LED adjacent to the green LED will light when a fire greater than 2 feet x 2 feet is detected (or whatever is the preset size threshold). If the siren switch is on then the MVFDS internal siren will sound the alarm state. If the siren switch is off the siren will not sound the alarm.

(3) DUMP Indicator

The red LED suppressor dump signal will light when a detected fire exceeds the suppressor dump threshold. If the UV switch is set to the AND position the dump signal will only occur if the UV detector also detects the fire (of course, if the UV detector switch is on).

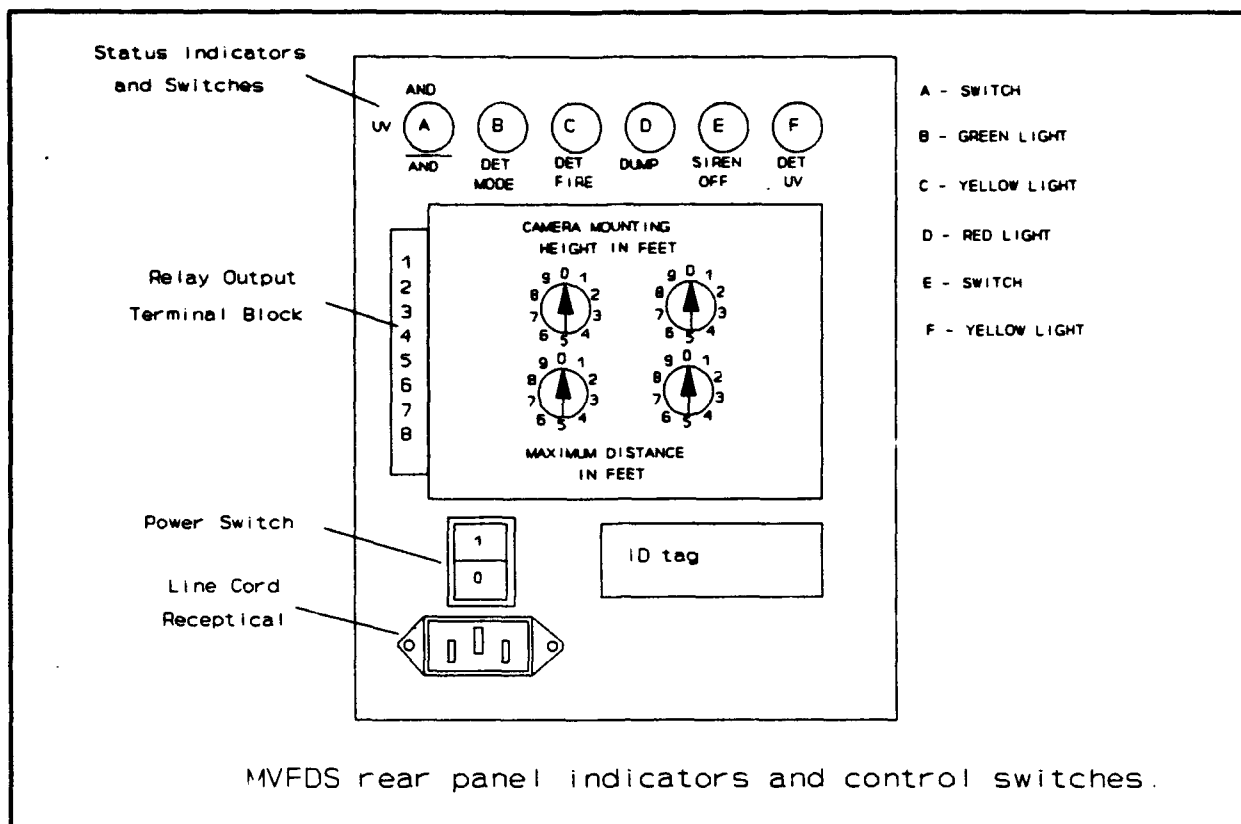


Figure 21. MVFDS Rear Panel Indicators and Control Switches

(4) DET UV Indicator

The yellow UV indicator pulses for UV levels below a preset detector threshold and produces a steady output if the UV levels detected are above the threshold.

d. Control Switches (See Figure 21)

(1) UV AND or NOT AND

The UV AND switch enables the logical AND of the UV detector steady state with the MVFDS dump output. IF the switch is in the AND position the UV detector must be satisfied with sufficient UV to allow a dump signal to be output by the MVFDS.

(2) Siren Off

The Siren Switch allows the internal siren, indicating a fire of some size and/or location, to be enabled or disabled.

e. Camera Mounting Parameter Switches

As shown in Figure 21, four rotary switches are mounted on the back of the rear panel box to provide camera mounting information input to the computer. The computer uses this information to calculate the distance to a fire and the fire size using the MVFDS perspective grid box software algorithms. The right hand switch in each horizontal pair is the unit digit and the left hand switch in each pair is the tens digit. The maximum possible input range for each pair of switches is 00 to 99; however, the ranges are restricted as described in the following.

The top pair of switches input two digits of the camera mounting height in feet above the floor or ground. The usable range for height is 8 to 15 feet.

The bottom pair of switches are used to input two digits of the maximum distance of fires to be detected in the vertical field of view. The usable range is 50 to 99 feet.

If the switches are not set within the specified ranges, the software will prompt the installer to provide the correct values in order to continue. (See Figure 22)

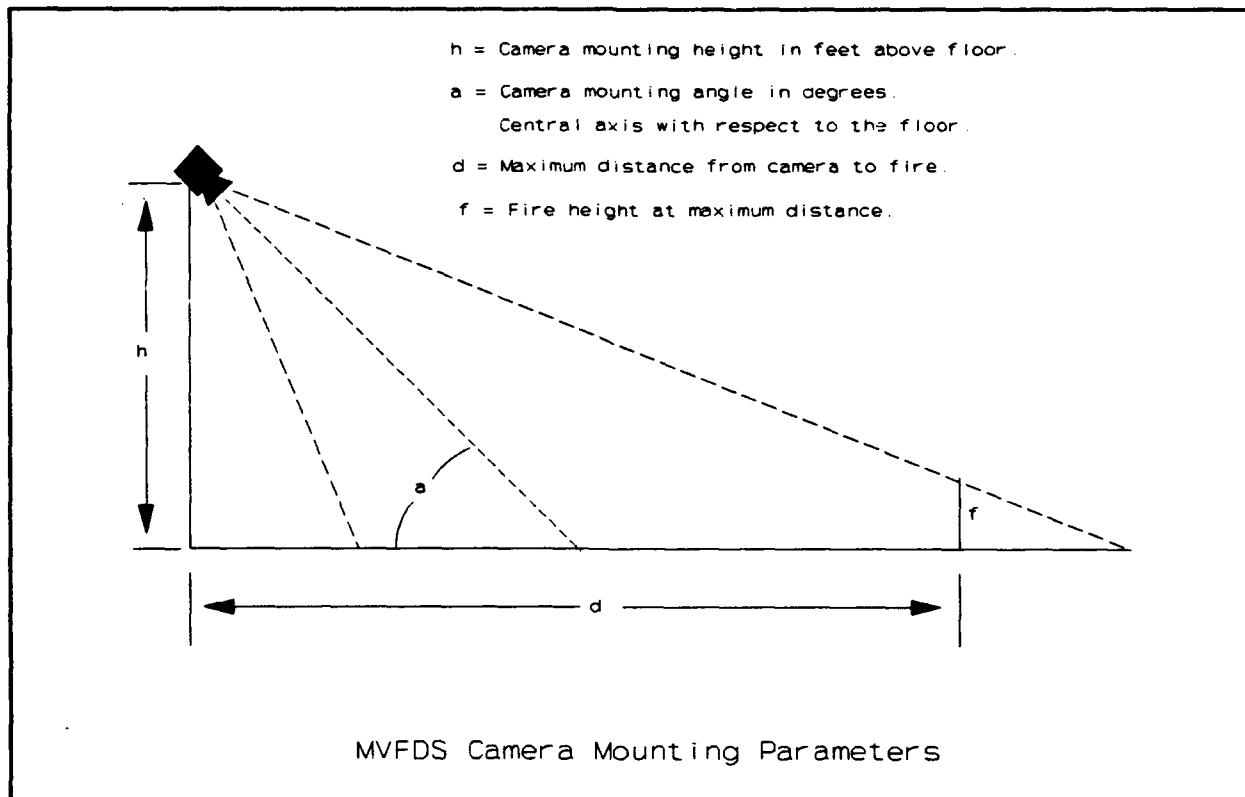


Figure 22. MVFDS Camera Mounting Parameters

f. Output Control Connectors

Normally open contact relay isolated outputs are available at the 8 point numbered terminal strip on the left side of the rear panel box. The connectors provide the user with signals for external remote status monitoring and dump activation. The contact rating specification for the relay contacts are 120V AC/DC at 1Amp maximums. The relay isolation breakdown voltage is 1000 Volts AC/DC minimum.

DET MODE	contact points 1 & 2
DET FIRE	contact points 3 & 4
DUMP	contact points 5 & 6
SPARE	contact points 7 & 8

g. Internal Connectors for user special operating modes (See Figure 23)

The following special connectors are available for the user to attach monitors and keyboard to run the system with software utilities during installation, special diagnostic and demo situations. These connectors are accessible by removing the cover of the rear panel box being careful not to stress the four rotary switch interface leads.

1. Keyboard Connector (See Figure 23)

The keyboard connector has a short interface adaptor cable nested inside the panel box which allows a standard keyboard connector to be connected to the host computer card. During the power up system boot the software checks to see if a keyboard is connected, proceeds with booting the primary MVFDS fire detection program, then allows halting the primary program to select and run other utilities stored in the ROM disk.

2. Frame Grabber Card RGB Analog Output (See Figure 23)

The RGB analog video output of the frame grabber card is available on a DB15 (15 pin) female connector. This output connector will accept a VGA or super VGA color display monitor connector cable. The connector is located near the top of the FG card right most rear access slot. This output displays the full 24bit RGB (16 million colors) color images stored in the FG card video memory. When the MVFDS is cycling in the normal fire detection mode the image displayed is captured at a longer integration time, 1/60 sec, producing a normal brightness level in subdued interior hangar lighting situations.

3. VGA Card Video Output (See Figure 23)

The RGB analog output of the VGA graphics card

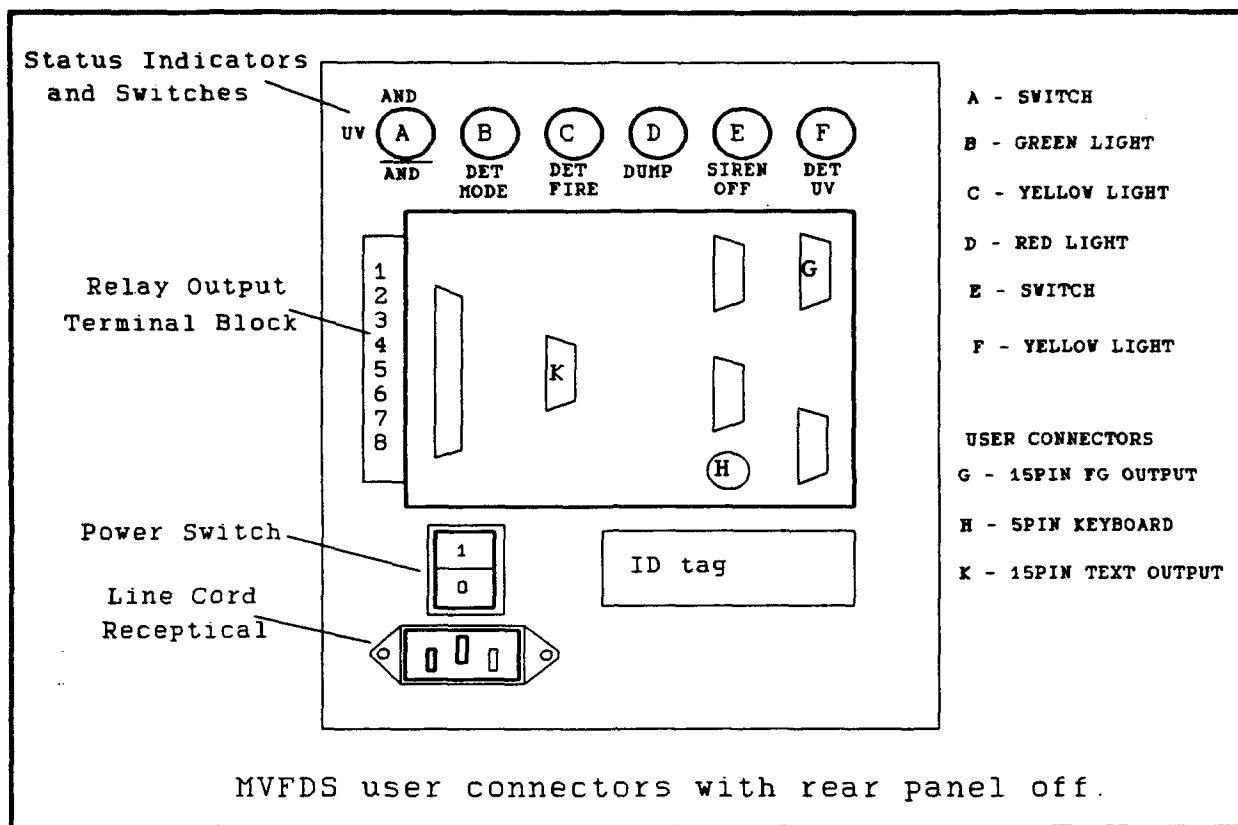


Figure 23. MVFDS User Connectors with Rear Panel Off

is available on a DB15 female connector. This connector is located near the middle of the VGA card rear access slot second in from the left side. This connector will accept a VGA color monitor or a VGA monochrome monitor to display the DOS text printouts of directories, program menus, program text statements, and all interactive programming when the keyboard is connected.

D. FIELD AND LABORATORY TESTING

The prototype systems have been subjected to ongoing laboratory and field testing throughout the development program. In the laboratory the systems have been tested with very small scale fires, simulated fires, a large variety of false alarm sources and video tape data from field tests. As the system reached final development stages the functional units were taken outdoors to perform field tests with larger fires and a variety of false alarm sources. Each level of hardware and software implementation evolved from the testing and revision cycles. The MVFDS design has narrowed in on a minimal set of specific hardware and software requirements. The minimal system can perform the fire detection program with extremely high reliability and moderate costs comparable with present discrete fire detector technologies.

E. APPLICATIONS

The primary goal of the development program was to develop a ground based MVFDS for hydrocarbon fire protection of aircraft, personnel and ground based equipment in operational aircraft hangars/shelters. Rapid, reliable intelligent machine vision fire detection and suppression can be applied in many other applications where a large number of complex variables must be considered to respond in very short critical decision periods.

F. MVFDS PRODUCTION HARDWARE

The prototype system hardware package was developed using standard off-the-shelf commercial microcomputer system components. This gave a great deal of capacity and flexibility in quickly implementing the system concepts in a reasonably compact portable system enclosure. The prototype system components offer a much greater capacity and flexibility than needed for the fire detection program storage plus enough space to include additional software utilities to meet the unexpected range of needs that may be encountered in the performance evaluation tests. The actual hardware and software storage memory requirements for the production hardware designs will be very much smaller in capacity, flexibility, weight, volume and power requirements.

G. CONCLUSIONS

The hardware required to implement the MVFDS exists in suitable low cost, low power, small size and reliable components readily available to package in single units for R&D, field testing, and operational installation in fixed ground based environments. Further refinement and simplification of the hardware/software system can reduce size and power while improving ruggedness for future production systems and a broader range of applications.

Newer subminiature cameras are becoming available which can further reduce system sizes. The control box electronics of the SONY camera contains much more electronic signal processing features than needed, PAL encoding, auto exposure lens control, power regulators, etc. These can be eliminated reducing the camera size to about one-fourth of the present size. The FG cards for IBM compatible computers are generally implemented on the 5-inch high by 13-inch long AT (Advanced Technology) card formats. These also have much more circuitry and processing features than necessary, including NTSC encoders/decoders, special effects, genlock, etc. Eliminating these unnecessary features and circuits can reduce the size by at least one half. The proliferation of low cost PC-AT miniaturized computer mother boards using VLSI chip sets with 11-inch x 13-inch standard size boards reducing to 3-inch x 3-inch boards, along with reduced size peripheral boards and power

supplies will yield greatly reduced system sizes in the next generation designs.

The extremely large numbers of microcomputer system, software, camera, FG card and I/O card manufacturers advancing the state-of-the-art in machine vision products dictate using popular mainstream technology. The continuing advances guarantee low-risk MVFDS hardware and software improvements yielding increased reliability and capability for future MVFDS designs.

SECTION V

CONCLUSIONS

A. ACCOMPLISHMENTS

The objectives of this Phase II effort were: (1) to develop a Machine Vision Fire Detector System (MVFDS) product; (2) to test its performance against a variety of fire threats and possible false alarm sources; and (3) to develop the means to make the product available to the Air Force as well as to the commercial/industrial sector. The Phase II effort was based upon the results of the Phase I feasibility study (see Reference 1).

The Phase I research effort verified the feasibility of (1) utilizing Machine Vision technology to identify fires and to discriminate them from nonfire (false alarm) sources; and (2) developing Machine Vision concepts that provide important real time information on fire event size and location/position. It was shown for the first time that a direct technique (as opposed to indirect techniques by current UV and IR detectors) could be used to determine actual fire size and location, which can be used as the basis to release automatically fire extinguishant agent in selected "zones" for preselected sizes of fires.

The Phase II effort was aimed at translating these "proofs-of-feasibility" into working hardware and software. A major factor underlying the objectives of the effort was the need to develop a detector that provided immunity to false alarms than current UV, IR, and combined UV/IR fire detectors. It was, therefore, a requirement to develop the Machine Vision Fire Detection System in such a manner that it provided intelligent decisions based upon actual properties of fire events. In other words, the MVFDS was developed to emulate a human's process of determining the physical, temporal, and spatial characteristics of an object or phenomena, comparing and analyzing such information with stored knowledge, and rationalizing the nature, size, location, and threat of the event.

In addition to satisfying the above objectives, it was deemed necessary to verify that the technology presents minimum risk to manufacture a reliable MVFDS product. The operational ability of the MVFDS functional prototype developed in this Phase II effort was demonstrated on several occasions to the Air Force. The ability to develop such a product from currently available state-of-the-art components was also proven. In addition, it was also verified that the MVFDS could be assembled at rather low cost from commercial parts, and that the cost of a manufactured, fully militarized and UL/FM-approved, commercial unit would be similar to standard UV/IR detectors today, and probably less in a system configuration.

In general, the effort was directed at satisfying the following fundamental Air Force goals related to fire detection:

1. Increase reliability of fire detection
2. Eliminate false alarm problems
3. Provide more specific information on fire type, size, location, and nature of event, thus allowing for "intelligent" detector decisions
4. Ability to be used in several applications
5. Higher performance specifications than current UV and IR detectors.
6. Adaptable to and compatible with current fire protection system installations

All of the objectives of this effort were met.

In summary, this program resulted in several accomplishments related to hardware and software. The following are several of the more important accomplishments.

1. Developed a physical model describing the spectral, spatial, and temporal properties of fire optical emissions.
2. Developed and implemented algorithms for the estimation of parameters of the fire model from sequences of color images.
3. Developed and implemented efficient structures for representing the image in terms of the scene and sensor geometry.
4. Developed and implemented an efficient decision process that combines estimates from the algorithms to produce a fire/no fire determination in real-time along with supporting size and location information if a fire is found.
5. Acquired significant insight from a large amount of experimentation with data and algorithms that will be valuable during further development and in the application of this technology to other applications.
6. Assembled standard commercial, off-the-shelf video, microprocessor, CCD camera, frame grabbers, and electronic components to produce a functional Machine Vision Fire Detector.
7. Developed the capability to process frames rapidly and to deduce the presence or nonpresence of fire within a time period of less one second.

8. Developed the capability of determining size, distance, and fire threat in real-time.

9. Developed appropriate algorithms and system functions to minimize false alarms.

10. Determined the feasibility and design approach for other applications, including aircraft.

B. POTENTIAL COMMERCIAL BENEFITS OF MVFDS

The advent of the MVFDS will provide a new market of interest to two sectors of high-tech industry. Fire detector manufacturers, military electronics manufacturers, and optical camera manufacturers are all viable candidates to produce an MVFDS product. Because the applications of the MVFDS design and concept cover a broad range, there are many potential customer outlets for its use. Intrusion detection, motion detection, damage assessment, identification/presence of persons or objects, status of environments/facilities (e.g., whether aircraft hangar doors are open or closed; whether aircraft or other object is present), fires associated with various objects in various locations, presence of unwanted objects such as UV (e.g., cracked light lens) and IR (e.g., hot bodies/fire ignition threats) sources, and discrimination between hydrocarbon and hypergolic fuel fires, are examples of how the MVFDS could be used in multiple or special purpose applications. The Air Force is already planning continued development of the MVFDS for such applications as aircraft dry bay and engine bay fire detection, as well as ground-based facility fire detection.

The MVFDS is an improvement over present conventional detectors and is an obvious replacement of or addition to existing installed systems, especially in more demanding complex applications. The availability of a more capable and reliable detector than "old technology" detectors offer will also have significant impact on controlling the accidental release of halons (CFCs) in the atmosphere due to false alarms. Also, less agent would be required to extinguish a fire because the MVFDS can determine where the fire is located, thus only releasing agent in that zone rather than a total flood as with today's technology.

Also, because of the added feature of the MVFDS to provide realtime video coverage of the area being surveyed by the MVFDS for fire, "man-in-the-loop" is an important attribute, especially for such applications as B-2 hangars and in-flight military/commercial aircraft fire detection. Never before has there been an aircraft fire detection system that brought the pilot into the decision loop and gave him direct evidence of whether to fire or not fire the extinguisher in the engine compartment when the "red alarm light" came on. Over the past 10 years there have been literally hundreds of false fire alarms and, perhaps worse, many missed fires.

The cost of camera/video and computer component hardware is decreasing at a very rapid rate. New, faster, more compact computers are entering the market on a regular basis. CCD cameras of only a few centimeters in size, that can process images at speeds of thousands of frames per second, are now available. The lifetime in the marketplace for computer processors, frame grabbers, random access memory chips, CCD cameras, and integrated logic chips is very short. From the time this project began to its completion, the cost of many of the major components was reduced by over 50%, yet the performance capabilities increased by over 100%. Today's design of an MVFDS will certainly cost considerably less two years later.

One immediate application of the new detector would be to integrate it with existing installed fire protection systems so as to provide a very large increase in the system's reliability and immunity to false dumps/alarms. The MVFDS can be easily retrofitted into current configurations and panels. The existing/installed UV, IR, or UV/IR detectors could be used as "ANDS" in the logic decision path and/or as "switches" to alert the MVFDS of the presence of such radiations, thus turning on the MVFDS "alert" mode (discussed in detail later).

Other possible applications include munitions/propellant production; commercial buildings; public facilities/buildings; areas/facilities/grounds requiring security as well as fire protection; industrial production/assembly lines; clean rooms; hypergolic fuel storage facilities (both fire and leak detection); commercial aircraft in-flight fire detection (cargo bay, engine bay, lavatories, and passenger compartments; naval ships; spacecraft and Shuttle assembly areas; etc.

SECTION VI

RECOMMENDATIONS

Based upon the accomplishments of this effort and the potential benefits/applications which the MVFDS has been shown to be able to provide, it is only prudent to recommend that the functional prototype be further developed for operational use by both the military and commercial sectors.

For aircraft applications, especially dry bay and engine bay fire protection, the MVFDS must incorporate other technologies such as fiber optics and fast speed CCDs. The detector must also be engineered into a compact, light weight, low power, and Mil-spec package, one that will also meet the environmental specifications of both commercial and military aircraft (e.g., Mil-Std-810D).

The unit developed herein, should also be further developed for operational use by the military in aircraft hangars, shelters, and support facilities. Another immediate need is to "field" the device for hot-pit fire protection on mobile platforms. Full scale development efforts aimed first at hangars, and second at other ground-based needs, should begin immediately. As part of this full scale development effort, several activities should be initiated: (1) detailed field testing within a simulated Hardened Aircraft Shelter (HAS) -type facility at Tyndall AFB; (2) continued false alarm testing and modifications of the algorithms; (3) value engineering of the design to reduce cost; (4) environmental design to meet environmental constraints and specifications; and (5) development of a dedicated board and perhaps a VLSI dedicated chip.

Also, other tasks should be conducted concomitant with the above full scale development and test efforts, such as: (1) integrate methods to automatically test lens cleanliness and calibrate the detector; and (2) develop modelling tools to automate the process of determining optimal system settings and algorithms from application domain descriptions in terms of factors such as fire type, scene geometry, and possible false alarm sources.

SECTION VII

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APPENDIX I

MACHINE VISION FIRE DETECTION PERFORMANCE CRITERIA

A. SCOPE

The following is a performance specification goal of the MVFDS for the specific application of fire detection in Air Force aircraft hangars and shelters. The performance goals are directed at exceeding the requirements of: (1) the current AFR 88-15, Criteria and Standards for Air Force Construction, January, 1986, which requires detection of a 10-foot x 10-foot JP-4 pan fire at 150 feet distance in five seconds after the event has reached this size; and (2) the requirements stated in ETL 90-09, Fire Protection Engineering Criteria for Aircraft Maintenance, Servicing and Storage Facilities, Directorate of Engineering and Services, Installation Development Division, Engineering Branch, Tyndall AFB, November 2, 1990, which require the detection of a 2-foot x 2-foot JP-4 pan fire at 100 feet in five seconds after the fire has reached this size. The goals, then, were to detect smaller fires at greater distances in less time, and to provide real-time measurements of fire size/growth, distance, location and threat.

Other applications may require the MVFDS to meet more stringent performance requirements which may include faster response times and detection of smaller events at greater distances. These increased performance features appear to be feasible, and are currently being developed for aircraft dry bay and engine bay applications under Air Force Wright Laboratories, WPAFB, sponsorship.

As stated in Section II, the goal of this first generation MVFDS development was to exceed this current AF specification by detecting fires in less time (e.g. less than the AF-specified 5 seconds; hopefully one second or less) and providing the value-added features which are described herein, such as determination of distance and fire size in real time. Also, it is a goal to detect smaller fires (less than 4 ft²) at distances of 100 feet or more, compared to the current AFR 88-15 requirement of 100 ft² size at 150 feet distance. This can be accomplished with optics by reducing the field-of-view (FOV). This overall goal was met by this development effort.

The following performance objectives are recommended for the "final product" after it has undergone "FSD" (Full Scale Development). These performance specifications do not pertain to the functional MVFDS unit developed in this Phase II SBIR. This functional unit used commercial parts to demonstrate the utility of the detector to meet the basic fire detection, fire size/distance, and false alarm immunity goals.

B. RECOMMENDED MVFDS TECHNICAL PERFORMANCE FOR A FULL SCALE DEVELOPMENT EFFORT

1. Fire Detection

a. Fire Size

The MVFDS shall be able to detect an aircraft hangar/shelter JP-4/hydrocarbon nominal fire of area (x-y coordinates) 4 square feet, and be capable of being modified to detect smaller fires, if required, through the use of appropriate optics to reduce the field-of-view and increase resolution.

b. Fire Distance

The MVFDS shall be able to detect a 2-foot x 2-foot square hydrocarbon-based fuel pan fire at a distance of 100 feet or less.

c. Fire Detection Time

The MVFDS shall be able to detect a 2-foot x 2-foot square JP-4/hydrocarbon-based fuel pan fire at a distance of 100 feet in less than one second after the fire has reached 2-foot x 2-foot (4 ft²) areal extent.

2. Determination of Physical Properties of Fire

a. Distance and Location

In a firmly mounted/fixed-in-place position, the MVFDS shall be able to determine the relative distance and location of a minimum-sized fire of 4 ft² area, located within the field-of-view of the detector at a range (for a 4 ft² fire) of 100 feet or less.

1. Field-Of-View of Detector

Each detector in the MVFDS shall have the capability of a field-of-view of up to 90 degrees, but be capable of reducing the FOV through the simple exchange of an optical lens.

b. Fire Size/Growth

The MVFDS shall be able to determine the projected size and projected growth rate of any fire equal to or greater than a minimal 4 ft² area within its field-of-view, at a distance of 100 feet or less, in time increments of one second or less.

3. Activation of Other Systems

a. Activation of Fire Alarms

The MVFDS shall be able to activate alarms at various locations to indicate the presence of a fire of 4 ft² or greater size within the field-of-view and detection range of the detector(s).

b. Activation of Fire Extinguishing System(s)

The MVFDS shall be able to detect and continue to monitor the size and location of a fire until such time that the measured size equals the predetermined fire size requirement (preset value). At such a time, the MVFDS shall activate the fire extinguishing system. If the fire has not reached the predetermined maximum size threat required for automated fire suppressant dump, the MVFDS shall continue to monitor the fire until the fire has either been extinguished or reduced to minimal size or until a predetermined period of time has elapsed and then activate the appropriate fire suppressor(s), or do nothing, if appropriate.

1. Activation of Specific Zonal Fire Extinguishing System(s)

The MVFDS shall be able to monitor the size, growth, distance and location of the fire until such time that the size and/or location meets the predetermined requirements for automated action to activate the entire fire suppressant system or only that part of the system which covers the specific zone/region in which the fire is located, should such a zonal system requirement be imposed.

2. Capability to Override Automatic activation Function and/or to Activate Manually the Suppression System

The MVFDS shall have the capability of providing a direct video output which can be monitored on a simple CRT monitor (TV) in a remote location, such as the Fire Station Control Room. This output will be the actual scene/sequence of the fire event being processed by the MVFDS. The "fire alarm" signal in the Fire Station would immediately alert the on-duty person that a fire is in process, which can be seen on the TV monitor. The on-duty dispatcher shall have the ability to override the MVFDS's automatic mode(s) via a manual switch and to discharge manually the appropriate suppressors if required. This ability will provide time for in-hangar crew to extinguish manually the fire, if possible, and will also help to minimize the amount of suppressant discharged to minimize environmental effects.

In addition to the manual override and suppressor activation switches in the Fire Station Control Room, manual switches shall be located on the MVFDS processor unit, and/or within the facility/area being monitored for fire protection, which when activated would prevent the MVFDS from executing an automatic release of the fire suppressant agent(s).

4. Fire Discrimination

The MVFDS shall, within its unobstructed field-of-view, detect a 2-foot x 2-foot square JP-4 pan fire at a distance of 100 feet in 1 second or less in daylight; darkness; presence of aircraft, vehicle, ground equipment, and indoor and outdoor lights of all varieties and intensity levels; and within the presence of any nonfire device, entity, operation or phenomena.

a. False Alarm Immunity

1. Facility, Outside, Photographic, Vehicle, AGE, and Service Lights

The MVFDS shall not identify any type of light of any color, or any intensity value, in any mode, including stationary, moving, rotating, flashing, or chopped, at any distance, with or without a "cracked" lens or with or without a lens cover, as a "fire."

2. Reflecting Surfaces

The MVFDS shall not identify any nonfire reflected light, including reflected sunlight, from any surface of any type of material or substance, as a "fire."

3. Aircraft Engine Effluents/Exhaust

The MVFDS shall not identify any type of aircraft engine exhaust emission, including engine start through all levels of power settings allowed in a hangar, as a "fire".

4. Aircraft Subsystems

The MVFDS shall not false alarm due to the presence of an aircraft subsystem or component.

5. Lightning

The MVFDS shall not false alarm due to the electromagnetic emissions from lightning, either directly in the field-of-view of the detector(s), or reflected in the field-of-view of the detector(s).

6. Sunlight

The MVFDS shall not identify sunlight, either direct, indirect/reflected, or filtered or chopped, as a "fire."

7. Welding/Cutting Tools/Operations

The MVFDS shall not identify any type of acetylene welding/cutting operation or any other type of welding operation of any type of material, involving any type of welding apparatus, as a "fire."

8. Hot Bodies

The MVFDS shall not false alarm in the presence of any black-body-type of source, regardless of its temperature, emissivity, and material type.

9. Electric Discharges/Arcing

The MVFDS shall not false alarm due to any form of electrical arcing that occurs within the field-of-view of the detector(s).

10. Personnel Heaters

The MVFDS shall not false alarm due to presence at any distance of a personnel heater device with Calrod element and variable fan.

11. Lit Cigars/Cigarettes

The MVFDS shall not identify a lit cigar or cigarette at distances equal to or greater than 2 feet as a "fire".

12. Matches/Lighters

The MVFDS shall not identify lit matches or lighters as "fire" at distances equal to or greater than 2 feet.

13. Communication Devices

The MVFDS shall not false alarm due to presence of radio communication devices, including 5 Watt Walkie Talkies, located at any distance from a MVFDS detector or a MVFDS Computer Processor unit.

14. Multiple Sources

The MVFDS shall not false alarm due to the presence of 2 or more of any of the above types of sources of UV, IR, and visible radiation.

b. Detection of Fire in the Presence of Nonfire Sources of UV, IR, and Visible Spectral Emissions

The MVFDS shall not be affected in its fire detection performance by the presence, in its field-of-view, of one or more sources of UV, IR, and visible radiation, whether or not in the direct line-of-sight of the detector(s), whether chopped or spectrally varied, and regardless of their intensities or motion, provided the object(s) do not obstruct the fire from the MVFDS detector's view.

C. CONFIGURATION

1. Detectors

a. Single

The MVFDS shall be able to be configured as a single detector unit and shall meet all the performance specifications for the area covered by the field-of-view of the single detector. The detector may either be integral to the MVFDS enclosure/container, or may be separated via cable from the MVFDS enclosure/container by up to 50 feet.

b. Multiple

The MVFDS shall be able to be configured with multiple detectors, linked to the computer processing enclosure unit via cable. The MVFDS unit shall be able to process the inputs of two or more optical CCD detectors.

2. MVFDS Module Unit

a. With Single Detector

The MVFDS Module Unit ("box" or container) shall contain the power supply, frame grabbing electronics, A/D converters, data storage memory devices, computer processor, I/O devices, appropriate output drivers, and video input. A single MVFDS detector may either be integral to the unit or connected via a cable of up to about 50 feet in length. It shall also contain, as an option, an input connector for other types of detectors, such as UV and IR.

b. With Multiple Detectors

The MVFDS Module Unit shall contain the power supply, frame grabbing electronics, A/D converters, data storage memory devices, computer processor, I/O devices, appropriate output drivers and video inputs. It will provide for two or more MVFDS detector cable inputs. Also, an input cable connector will be provided for a non-MVFDS UV/IR detector controller output signal as

an option, if required.

c. Compatibility with Previously Installed UV/IR Detectors and Controllers

1. UV/IR Detectors

The MVFDS shall be able to incorporate as direct input into its logic, the outputs of UV/IR detectors that may have already been installed in the facility. The UV/IR input shall add an "AND" to the MVFDS logic but shall not affect the MVFDS decision process. The UV detector input shall be integrated into the MVFDS as an "option" which could be used as part of the fire detection logic process. A switch shall be provided to either incorporate the detector or to remove it from the process.

2. Controllers

The MVFDS shall be compatible with existing fire protection system controller units and shall be able to provide compatible electrical inputs to cause suppressant activation and/or alarm initiation.

d. Compatibility with Video Monitoring Terminals

The MVFDS shall be capable of displaying a video image of the field-of-view and/or the fire event, on a remote CRT unit, such as in the Fire Station monitoring/communication room. The MVFDS will provide the capability for visual inspection, verification of fire, and visual identification of location of fire, if required.

D. OTHER DESIRABLE FEATURES OF A PRODUCTION MVFDS UNIT (NOT NOW PROVIDED IN THIS FUNCTIONAL FIRST GENERATION UNIT, ALTHOUGH FEASIBLE IN PRODUCTION UNITS)

1. Automated Internal Operation Test

a. Electronics

The MVFDS shall have the capability of monitoring its operational integrity and performance level. Should any interruption of power occur, a fault alarm light exterior to the MVFDS's enclosure and in the Fire Station, shall be illuminated, if required.

The MVFDS, through Built-in Test Electronics (BITE), shall determine/test its ability to detect the specified size fire at the specified distance in the specified time. This test shall be conducted automatically once each hour (or as specified by the user) in a time period of less than 250 milliseconds, unless a fire detection operation is in process.

2. Window Cleanliness

As part of its BITE, the MVFDS shall also determine the cleanliness of its window and ability to resolve appropriate colors. Any degradation of this ability that would affect the MVFDS's ability to perform to specification, will cause a fault light (LED) alarm to be activated.

3. Environment (Requirement if Specified by the AF as MIL-Standards)

The MVFDS enclosure/container shall be explosion proof to NFPA Class I Groups B, C, and D, Class II Groups E and G, Flameproof to Exhibit 5; Weatherproof to NEMA 4, water tight and dust tight. It shall also meet the following military standards:

a. MIL-STD-810D

1. Section 501.1 High Temperature: The high temperature requirement shall be 60 degrees C (140 degrees F).

2. Section 502.2 Low temperature: The low temperature requirement shall be -34 degrees C (-30 degrees F).

3. Section 512.2 Leakage (Water Immersion): Per the stipulations of the military standard with the addition of the following: A water jet applied at right angles to front and side surfaces of the MVFDS from a distance of 2 meters. The jet shall be derived from a nozzle having an orifice diameter of not more than 6 mm (0.25 in) and a nozzle pressure of 345 +/- 105 Kpa (50 +/- 15 psi).

4. Section 511.2 Explosive Atmosphere: Test per the stipulations and procedures in the military standard.

5. Section 516.3 Shock: The MVFDS shall withstand the following shock without being mechanically damaged.

"After three shocks in each of three planes of 500g +/- 50g of 0.5 ms duration (or shock with the same energy content) the MVFDS shall perform as specified."

"After 10 shocks of 10g +/- 1 g of 60 ms duration in each plane, the detector shall operate as specified."

6. Section 514.3 Vibration: The MVFDS shall meet the requirements specified for Category 8, ground vehicles mobile.

7. Section 500.2 Altitude: The MVFDS shall function correctly at sea level pressure and up to altitudes of 3,000 meters.

8. Section 510.2 Sand and Dust: Per the stipulation of the military standard.

b. Military Standards 461C and 462C, Electromagnetic Waves

The MVFDS shall pass such tests as prescribed in paragraphs CEO3, CEO7, CSO2, CSO6, REO2, RSO2, and RSO3, as so defined within the category A1c, "Aerospace Ground Equipment Associated with Aircraft."

c. Reliability

1. MTBF

The MVFDS shall have a mean-time-between-failure (MTBF) of at least 50,000 operational hours.

2. Mission Success

The MVFDS shall have a mission success reliability of at least 0.999 in detecting the specified fire at the specified distance in the specified time.

The MVFDS shall have a reliability of 0.999 or greater in not falsely activating the suppressant system due to a nonfire source.

d. Logistics

The MVFDS shall be easily maintained in the field using replacement pc-boards and optical detector units.

E. VERIFICATION OF PERFORMANCE SPECIFICATIONS

The ability of the MVFDS to meet the performance specifications stated herein shall be demonstrated by test to the system level. The recommended tests are included in Appendix II.

F. FALSE ALARM IMMUNITY

Immunity to false alarms is a critical performance feature of optical fire detectors. There are many types of nonfire sources of UV, visible, IR and ionizing radiation that could cause UV and/or IR optical fire detectors to false alarm. However, only those sources of visible radiation which emulate "flame properties" can possibly satisfy any one or more of the MVFDS's fire discriminators. Categories of nonfire sources of visible radiation are given below. During its development, many of these sources were utilized in the development of the MVFDS's discrimination algorithms.

Categories of Possible False Alarm Sources Having Visible
Radiation Emission

1. Lights

a. High-Intensity Discharge (HID) Lamps

1. High-Pressure Sodium
2. Mercury Vapor
3. Metal Halide
4. Low-Pressure Sodium
5. Xenon

b. Fluorescent Lamps (96 inch length)

1. Cool White
2. Deluxe Cool White
3. Warm White
4. Deluxe Warm White
5. White
6. Daylight
7. Black Light

c. Incandescent Lamps

1. Quartz Tungsten Halogen
2. Sealed Beam - Automotive:
3. Headlamp
 - a. Spotlamp
 - b. Signal
 - c. Light Bar
 - d. Rotating Lights
4. Flashlight
 - a. With Red Lens
5. Rough Service
6. Movie Projector
7. Blue Green Dome Light
8. Red Light
9. Vehicle Infrared Light

2. Reflected Light

Solar and/or artificial light reflecting from painted surfaces, metallic surfaces, plastics, standing water, ice and glass.

3. Natural Phenomena

- a. Sunlight: direct, scattered, reflected
- b. Lightning

4. Electrical Discharge

- a. Arcing
- b. Power Transformers
- c. Motors
- d. Electrical Devices
- e. Faulty Wiring

- f. Flashlamps
- g. Carbon Arcs

- 5. Electromagnetic Waves (EMI): to be tested only if the detector must pass Mil-Std-461/462 EMI.
 - a. Communication Devices/Walkie Talkies/Radios/TV
 - b. Radar
 - c. Electric Power Switching
 - d. EMI from Electronic Equipment:
 - e. Vehicle/Aircraft/Equipment Subsystems
 - f. Electronic tools/equipment
 - g. Microwave devices
 - h. Weapon Systems

- 6. Personnel Items (very doubtfully near facility)
 - a. Lighted Cigarette, Cigar, Pipe
 - b. Matches (paper and wood)
 - c. Butane Lighter

- 7. Tools/Operations
 - a. Welding Operations
 - b. TIG
 - c. Arc
 - d. MIG
 - e. Acetylene Welding and Cutting Operations

- 8. Hot Bodies (that reach "red" color)
 - a. Radiator Heaters (1.0 and 1.5 Kw with Fan)
 - b. Radiator Kerosene Heater (70,000 BTU with Fan)

- 9. Security Personnel Weapons-Flashes

The characteristics of the above sources are given in detail in Reference 1, "Characteristics of Optical Fire Detector False Alarm Sources and Qualification Test Procedures to Prove Immunity," Goedeke, A. Donald and H. G. Gross, Final Report, TR-91-62, Contract No. F08635-91-C-0129, October 8, 1992: Sponsor, HQ AFCESA/RACF, Tyndall AFB, FL.

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APPENDIX II
RECOMMENDED TEST PLAN

A. INTRODUCTION

The following proposed test plan recommends procedures to test the performance of the MVFDS. The preliminary Performance Specification is addressed in Section II-B and should be referred to during the planning of any tests. This test plan may be augmented during the course of the tests and is not intended to be a rigid qualification test. Also, this SBIR Program is a "best effort" R&D program aimed at developing a new concept and demonstrating its functionality for various Air Force applications. It is not directed at developing an operational prototype. The test program defined herein is, in essence, a continuation of many preliminary, day-by-day tests that have been routinely conducted in developing the hardware and software.

As a basis of testing the MVFDS, it's purpose and application must be taken into account. The original objective of the MVFDS was to provide fire detection/protection for Air Force aircraft hangars, shelters, and related operations. The application potential of the detector has grown considerably and now includes crash rescue vehicle fire detection and ranging for automatic turret operation; in-flight aircraft dry bay fire/explosion detection; aircraft engine bay fire detection; aircraft cargo bay overheat and fire detection; facility overheat/fire threat detection; and munitions fire/explosion detection. Although these additional applications are being considered, they all require algorithms and data processing times that may differ from those associated with this first generation functional MVFDS unit. Therefore, in these tests, prime attention should be given to the aircraft hangar/ facility application.

The tests described herein should be conducted inside a hangar such as a HAS unit at Tyndall AFB, and/or in some structure such as a flow-through shelter. Also, video/computer tests and many false alarm tests can also be conducted in an inside test laboratory environment such as in the Donmar Ltd. facility.

1. Performance Characteristics to be Tested

a. Ability to Detect Fire

The first performance test is to determine the detector's ability to detect a hydrocarbon fuel fire and to alarm to its presence. The fuel type shall be JP-4, although JP-8 will suffice.

The fire sizes to be included in the tests shall be

1-foot x 1-foot, 2-foot x 2-foot, and 4-foot x 4-foot standard square pans. The pans should be made of a rigid material such as aluminum, or have internal cross bars to provide rigidity, and have a depth of about 4 inches.

b. Ability to Determine Size of Fire and to Cause an Automatic Release of Suppressant when Fire has Reached Programmed Size.

(1) The MVFDS shall be able to be programmed to alarm when fire is identified and to execute an action to cause the release of suppressant when the fire reaches the specified size/threat.

(2) The detector shall be programmed to effectuate an executive action to dump suppressant when the fire reaches the size of 2 feet x 2 feet and 4 feet x 4 feet, when the fires are located at distances of 50 feet and 100 feet, respectively.

c. Distance/Location of Fire to Detect

The ability of the detector to identify various size JP-4 fires at various distances shall be tested. The 1-foot x 1-foot fire shall be set at distances of 25 feet and 50 feet. The 2-foot x 2-foot fire shall be tested from 50 feet to as far as possible, typically about 150 feet. This distance is the current Air Force requirement for detection of a 10-foot x 10-foot fire. The 4-foot x 4-foot fire shall be tested at 100 feet and further, if feasible.

(1) Ability to Detect Fires in the Field-of-View.

It shall be shown that the MVFDS can identify the above size fires at their specified distance within the field-of-view of the lens (60-degree lens supplied).

(2) Ability to Determine Distance of Fire

The MVFDS shall be able to determine the distance of the fire from the detector. This will be demonstrated via an output from the MVFDS. This distance test shall utilize a 2-foot x 2-foot pan fire at 50 feet and 75 feet; and a 4-foot x 4-foot pan fire at 100 feet.

d. Time to Detect Fire

The time to detect a fire of the above sizes at the above distances shall be measured. The goal is to detect such fires as fast as possible, but typically in much less time (i.e., less than 1 second) than the current AF requirement of five seconds or less after the fire has reached a size of 10 feet x 10 feet.

2. Immunity to False Alarm

The detector shall be exposed to sources of UV, visible, and IR radiations which emanate from such common sources as lights, heaters, aircraft, sun, lightning, electrical discharge, and other items so stated herein. These sources shall be located in the field-of-view of the detector at distances which they would normally occur in the hangar/shelter or other application. In a hangar environment, where the detector would be mounted about 10 feet above the floor, distances of from 5 feet to the length of the facility, should be used. Tests should be conducted with both single false alarm sources as well as with and multiple false alarm sources. The light sources shall be modulated/chopped by people walking between the sources and detector or by fans or other variable speed devices. They should also be turned on and off several consecutive times.

During the fire detection/burn tests described above, selected sources of direct and reflected visible radiation shall be located in the same field-of-view as the fires.

Video tapes of false alarm stimuli are also to be used to demonstrate detector immunity. These videos shall contain scenes of lights and color reflecting/emitting items. They shall also contain images of real fires of the sizes and distances specified above.

Categories of nonfire sources of visible radiation to be considered in these tests are given above in Section II-C. Detailed characteristics of many items within these categories are contained in Reference 1, "Characteristics of Optical Fire Detector False Alarm Sources and Qualification Test Procedures to Prove Immunity," by Goedeke, A.D., and H. G. Gross, Final Report, TR-92-62, Contract No. F08635-91-C-0129, October 8, 1992: Sponsor, HQ AFCEA/RACF, Tyndall AFB, FL.

Specific tests which include combinations of the items listed in Table 1 shall be performed according to the procedures stated below. These items are all associated with Air Force aircraft, hangars, shelters, and ground equipments (AGE), to which the MVFDS would be exposed in an operational scenario.

TABLE 1

MAJOR LIGHT SOURCES EXPOSED TO THE MVFDS

<u>ITEM</u>	<u>MODEL</u>	<u>WATTAGE</u>
1. Metal Halide Lamp	MVR 1000/U	1000 Watts
2. Mercury Vapor Lamp	H33HL-400/DX	400 Watts

3.	High Pressure Sodium Lamp	Lucalox, LU1000	1000 Watts
4.	Metal Halide Lamp	MH 250/U	250 Watts
5.	Metal Halide Lamp	MVR 1500/HBU/E	1500 Watts
6.	Low Pressure Sodium Lamp	SOX35W, L70RB-35	35 Watts
7.	Mercury Vapor Lamp	H39KB-175	175 Watts
8.	F-16 Landing Light	GE4581	450 Watts
9.	F-16 Refueling Light	4028-1	15.4 Watts
10.	Aircraft Parking Lamp	1829	3.92 Watts
11.	Quartz Tungsten Halogen Lamp	T-3	300 Watts
12.	Truck Headlamp	GE4811 (43 Watts low beam; 53 W High	
13.	Yellow Strobe Lamp	Tandy 49-527	2.4 Watts
14.	Red Flashing Warn. Lamp	Tandy 42-3040	40 Watts
15.	Soft White Incandescent	GE	150 Watts
16.	Clear Incandescent Lamp	GE	150 Watts
17.	Dual Fluorescent Lamps	Sylvania F40	69 Watts
18.	Flashlight with and without IR lens		

a. Ability to Discriminate Fire from False Alarm Sources

While in the presence of the above nonfire sources of light/radiation, a 2-foot x 2-foot JP-4 pan fire shall be set at a distance of 75 feet; and again at 100 feet.

b. Ability To Function as dual Detector/Camera Input System.

The MVFDS shall be tested to detect the fires specified above, and to discriminate false alarm sources as so defined herein, using two detector heads/CCD cameras located at least 25 feet apart.

3. Test Procedures

a. Fire Burns

Two types of fire burns will be conducted. The first type will involve JP-4 as the fuel. The second will use rags soaked in a combustible oil.

(1) JP-4 Fires

Square aluminum or steel burn pans will be filled with water up to 1 inch below the brim. 8 ounces of JP-4 per 1 square foot of pan will be poured over the top of the water. At time zero the fuel will be ignited at one of the edges of the pan using either a spark gap electric discharge or a butane lighter such as used to light barbecues.

(2) Oil Rag Fires or Row of Pans

A 4-foot and 10-foot length of rags, of about 6 inches thickness, will be soaked in a combustible oil or kerosene. The rag will be stretched out to full length, normal to the MVFDS camera, and lit with a match or lighter at one end. This type of fire will be used to determine growth, growth rate, and fire size measurement capabilities of the MVFDS. A row of pans can be used instead of a long length of rags.

b. Detector Mounting

The mounting of the detector will depend upon the type of test being conducted. In tests in the lab, the detector may be mounted on a very sturdy tripod.

In tests inside a hangar/HAS unit, the detector will be hard mounted against the side of the facility, at a height of between 8 and 13 feet. The mounting bracket will be adjustable to set the "angle-to-the-floor" of the center line axis of the detector's field-of-view" to allow for distance calibration. The "thumb" roller switches on the MVFDS's console shall then be set according to the height above the floor of the detector lens, the angle of the center line axis of the FOV to the floor, and the FOV of the lens (see Section IV).

c. False Alarm Source Testing

The procedures should follow the general format of those described in Reference 1, "Characteristics of Optical Fire Detector False Alarm Sources and Qualification Test Procedures to Prove Immunity, Goedeke, A. Donald, and H. G. Gross, Donmar Ltd., Appendix II, dated October 8, 1992, Final Report, TR-92-62, Contract F08635-91-C-0129, Tyndall AFB, HQ AFCEA/RACF. Sections 8.0, 9.0, and 10.0 are especially relevant to qualification test

procedures for the testing of false alarm immunity when either single or multiple sources are present. The test procedures cover both stationary objects and phenomenon and moving objects. In addition, the chopping effect should also be imposed at a frequency of about 1-5 Hz. This can be simulated by a person walking rapidly back and forth through the field-of-view.