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SURVEY OF FIRE DETECTION TECHNOLOGIES AND SYSTEM EVALUATION-CERTIFICATION METHODOLOGIES AND THEIR SUITABILITY FOR AIRCRAFT CARGO COMPARTMENTS (NISTIR-6356)

by

[Thomas Cleary and William Grosshandler]

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United States Department of Commerce
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ABSTRACT

As part of the National Aeronautics and Space Administration (NASA) initiated program on global civil aviation, NIST is assisting the Federal Aviation Administration in its research to improve fire detection in aircraft cargo compartments. Improved fire detection includes both fast (early) fire sensing and immunity to nuisance alarms caused by environmental conditions and hardware faults. Aircraft cargo compartment detection certification methods have been reviewed. Current methods are not capable of evaluating the performance of multi-element detectors, nor detectors based on sensing fire signatures besides smoke; they must be upgraded for that capability. Component testing of detectors that sense chemicals, heat, smoke, or combinations and that might employ complex signal processing algorithms is a challenge. The Fire Emulator/Detector Evaluator (FE/DE) has been designed to evaluate fire detection technologies such as new sensors, multi-element detectors, and detectors that employ complex algorithms. The FE/DE is a flow tunnel that can reproduce velocity, temperature, smoke, and combustion gas levels to which a detector might be exposed during a fire. It is being upgraded to include low temperature operation and moisture variations found in aircraft cargo compartments. In addition, environmental sources such as dust and humidity can be produced to assess the level of immunity to nuisance alarms. A scientific literature survey and patent search have been conducted relating to existing and emerging fire detection technologies, and the potential use of new fire detection strategies in cargo compartment areas has been assessed. In the near term, improved detector signal processing and multi-sensor detectors based on combinations of smoke measurements, combustion gases and temperature are envisioned as significantly impacting detector system performance. Because of the required conversion of most Class D cargo compartments to Class C, a three-fold reduction in nuisance alarm rates will be required to maintain the status quo. If, in the future, detectors employ advanced signal processing with more robust sensing, the resulting nuisance alarm rate reduction would accomplish this and more.

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1.0 Introduction

The National Aeronautics and Space Administration (NASA) committed part of its allocated funds to pursue commercial aircraft safety issues by implementing an Office of Aeronautics and Space Transportation Technology (OASTT) program on global civilian aviation safety. This multi-year effort has the goal of reducing the aircraft accident rate by a factor of five in 10 years and by a factor of 10 in 20 years. The Federal Aviation Administration (FAA) Technical Center and the National Institute of Standards and Technology's Building and Fire Research Laboratory were enlisted to assist with aircraft fire safety issues. The FAA identified cargo compartment fire detection as an area of interest. A recent rule change requires that many aircraft cargo compartments be retrofitted with detection and suppression systems where previously none were required. The false alarm history of aircraft smoke detection systems is generally regarded as poor. Improvements in cargo compartment detection will impact aircraft safety by providing early and reliable fire detection and substantially reducing the nuisance alarm rate.

1.1 Background

Current detection technology used in aircraft cargo compartments relies mostly on particulate sensing by light beam scattering or ionization type detectors. They may be utilized in an aspiration system or in a spot arrangement located on the compartment ceiling. In general, these systems perform their intended function of alarming at a particular smoke level and experiencing false alarm infrequently. Cargo compartment detectors are designed to alarm at smoke levels between 4% and 16% obscuration per 0.305 m (1.00 ft).[1] The detection threshold is set well above the typical particulate background levels and redundancy limits hardware faults. However, false alarms are still present with estimates of the ratio of false alarm to fire ranging to 500:1.[2] Recently, analysis of incidents reported in Service Difficulty Reports (SDR), which are required to be submitted to the FAA after a smoke detector alarm event, indicates a ratio of approximately 100:1.[3] The frequency of false alarms has been estimated at 44 per million departures, while the frequency of fires in Class C and D compartments has been estimated at 0.085 per million departures.[4] With the rule change mandating conversion of Class D compartments (which required no detection or suppression systems) to Class C (which requires both detection and suppression), the absolute number of false alarms should increase in proportion to the increase in spaces protected, or approximately threefold. A false alarm requires unnecessary actions including flight delay, diversion, suppressant discharge, and aircraft evacuation. Every false alarm also erodes confidence in the system; thus it is desirable to reduce them to a very low level.

Aircraft cargo compartment detection systems are designed to meet performance criteria laid out in Federal Aviation Regulations (FAR) Section 25.858, "Cargo or Baggage Compartment Smoke or Fire Detection Systems,"[5] which states:

> *If certification with cargo or baggage compartment smoke or fire detection provisions is requested, the following must be met for each cargo or baggage compartment with those provisions:*
> *(a) The detection system must provide a visual indication to the flight crew within one minute after the start of a fire.*
> *(b) The system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the airplane is substantially decreased.*
> *(c) There must be a means to allow the crew to check in flight, the functioning of each fire detector circuit.*
> *(d) The effectiveness of the detection system must be shown for all approved operating configurations and conditions.*

This FAR does not preclude any particular fire detection technology. In practice, detection systems are usually photo-electric aspirated or spot-type detectors or ionization spot-type detectors. Temperature detectors may be used as a backup device, but no performance guidelines are expressed in various regulatory and guidance documents.

It may be feasible to reliably detect fires much smaller in size than one which produces enough smoke to make a current detection system alarm within the one minute time frame. This could allow for better control of the fire by the suppression system. New technologies, including advances in signal processing and sensors, have the potential to greatly reduce nuisance alarms while simultaneously decreasing time to detection. The fire detection industry is moving in a direction to utilize advances in technology in order to increase the sensitivity of fire detectors and reduce false alarm rates.

In cargo compartments, false alarm stimuli may include non-combustion aerosols such as dusts and condensed vapors, temperature and humidity swings, and engine emissions while on the ground. In principle fire detectors may sense something other than just the smoke aerosol. The alarm threshold levels of fire gases, radiation, temperature or other characteristics of fire must be specified. Current standards for fire detectors are not capable of evaluating a detector's immunity to false alarm stimuli, nor for evaluating detection systems that rely on new sensing technologies, nor multi-sensor devices. The objectives of this paper are to examine new sensing technologies and their applicability to cargo compartment detection, and to describe methodologies for evaluating these technologies.

1.2 Cargo Compartment Environment

An aircraft cargo compartment is described below in generic terms encompassing a wide range of environments and configurations presently found. In a typical passenger transport aircraft, the approximately cylindrical fuselage is separated into the main deck and the lower cargo compartments by the floor of the main deck. In a typical cargo transport configuration a single deck is used for cargo. Cargo compartments are classified by the aircraft configuration, compartment size and ventilation air flow.[6] Class A and B compartments are accessible in flight, such that a fire would be easily discovered by a crewmember at his station (Class A), or an approved detection system would alert the pilot or flight engineer (Class B.) Class C compartments have provisions for detection and suppression of fire and control of ventilation air flow. Typically, a ventilation control valve can be closed after the indication of fire. This functions to limit oxygen flow into the compartment and to decrease the loss of suppressant after discharge. Class C compartments can have ventilation air flows on the order of 0.24 m^3/s (500 cfm) or higher. Blake and Hill surveyed Class C compartments in the early 1980's and found them to range in size from 20.8 m^3 to 176 m^3 (735 ft^3 to 6200 ft^3).[7] Presently, the size range for domestic aircraft is 19.8 m^3 to 85 m^3 (700 ft^3 to 3000 ft^3).[4] Class D compartments require no provision for detection or suppression. The original rule for Class D compartment was that the sum of the volume in cubic feet and the air flow (ventilation or leakage) in cubic feet per hour (cfh) be below 2000. Thus, a 1000 ft^3 compartment would require a ventilation or leakage flow of 1000 cfh or less. The idea for this classification was that any fire would suffer oxygen starvation due the relatively small size and the limited air flow. The regulation was amended in 1986, reducing the space limitation to 28.3 m^3 (1000 ft^3) for new Class D compartments.[8] Class E compartments are only found on airplanes used exclusively for cargo transport. They have a smoke or fire detection system that alerts the pilot or flight engineer. There are means to control and shut off ventilating airflow and to prevent hazardous smoke and flame from entering the flight crew compartment.

A recent amendment to FAR 25.857 eliminated Class D compartments for certain transport category airplanes.[9] Affected Class D compartments will be converted to Class C by the inclusion of detection and suppression systems or converted to Class E if the aircraft is dedicated to cargo transport. This rule affects approximately 3300 aircraft in the United States.

Cargo is loaded into a compartment either inside individual containers (containerized) or loosely as is frequently done with passenger luggage (bulk loaded). Cargo may occupy nearly all of the compartment volume at times. The environment in a cargo compartment experiences a range of temperatures and pressures under normal conditions. Most Class C and D compartments are located inside the pressurized portion of the aircraft, the exception being Class D compartments located outside the pressurized portion of the cabin in some small aircraft.[4] Typically, the temperature ranges between ambient ground or cabin temperature and somewhat colder temperatures depending on the flight time, altitude and ventilation air flow. The pressure lies between ambient ground atmospheric pressure to approximately the pressurization level at 3050 m (10,000 ft or 0.69 atm.)

Animals and perishable fruits, flowers and vegetables can be transported in these compartments; thus conditioned air must be provided. Spraying vegetation after loading, just prior to compartment door closing, leaves a residual aerosol. Livestock are also a source of humidity and in addition emit CO_2, CO and CH_4. Dust is kicked up during loading and off-loading cargo. Exhaust emissions from taxiing aircraft and ground vehicles may be picked up by the air intake. All of these situations can lead to nuisance alarms. (Humidity and condensed moisture have been directly implicated as a source of unwanted alarms with current smoke detectors.[2,10]) Measurements of gas concentration and particulate levels in cargo compartments have not been reported, but must be known or estimated so that detector sensitivity is set above the expected background.

1.3 Fire Signatures

The process of combustion releases energy and produces gaseous, solid and condensed liquid products. The specific products formed and energy released depends on the composition of combusting materials, its burning rate, the oxygen concentration, and the mode of combustion. Certain solid materials may experience flaming or smoldering modes of combustion. Heated materials can undergo pyrolysis which is treated as a fire event since it produces smoke and gases and can transition to a flaming fire. The fuel source for cargo compartment fires is as varied as the cargo being transported. An FAA-Navy detector testing considered a number of fire scenarios: a cardboard box filled with shredded paper, a pan of kerosene, a cloth suitcase, a rigid plastic suitcase, a cardboard box filled with polystyrene packing, and polyurethane foam.[11] A suitcase full of clothing forced to pyrolyze and smolder was used in an aerosol can fire and explosion study performed by the FAA.[12]

Jackson and Robbins studied European detector test fires and characterized the amounts of CO, CO_2, H_2, smoke and temperature rise at the detector test location.[13] Grosshandler discussed the physical and chemical transformation of fuel during a fire and reviewed measurements of candidate signatures for early fire detection.[14] Cleary *et al.* characterized the effluent from two standard smoldering fire sources.[15] While there is typically enough information to develop detectors that will sense fire signatures, the levels expected with a specified fire in a particular compartment are needed to set alarm points. For smoke concentration, alarm levels have been determined from full-scale experimental testing. An experimental program at the FAA Technical Center to develop standard cargo compartment fires and to quantify their output is generating information that will be useful for design and testing of other types of detectors.[16]

2.0 Detector System Evaluation

The performance objective of fire detection in cargo compartments is to sense a burgeoning fire at a small enough size such that designed mitigation strategies including discharging suppressant, shutting off compartment ventilation, diversion to the nearest acceptable airport, and evacuation can effectively limit the fire damage and the life safety hazard. The lower limit of the fire size is bounded by detection limits of fire sensors, their locations and the fire location. If convected heat, gaseous chemicals or particulates are to be sensed, compartment flows and temperature gradients that must be overcome by plume buoyancy to transport the fire products to sensor locations are important. Full-scale cargo compartment fire tests performed in the past have established a fire size limit which was translated into the smoke concentration range and detection time of five minutes after the start a test fire. With the adoption of FAR 25.858 in 1980, the detection time was reduced to one minute.

Aircraft cargo compartment fire detection systems are evaluated through a certification process specific to the industry. The FAA has mandated the certification process through a series of Technical Standard Orders (TSOs) and Federal Aircraft Regulations (FARs) which deal specifically with smoke detection. A complete methodology does not exist for evaluating detectors that sense something other than smoke. Techniques that could be used to certify other types of detectors and improved techniques for certifying smoke detectors could improve reliability and facilitate implementation of new technologies. The current certification method, consisting of evaluation of component smoke detectors and certification of a designed system installed on a specific aircraft, is detailed below.

2.1 Current certification methods.

Fire detection and protection of cargo compartments was identified as a necessary safety measure following the rapid growth in passenger air transportation following World War II. The evolution of safety improvements continues today with the realization of Class D to C conversions taking place now. One unwanted result of cargo compartment fire detection is the negative impact of nuisance (false) alarms. A nuisance alarm is defined as any alarm not caused by a fire. Nuisance alarms fall into two distinct categories: alarms caused by environmental effects where the detector is located (dust, humidity, air velocity, temperature, etc.), and malfunctioning or poorly maintained equipment. One way to address the nuisance alarms due to environmental effects and infrequent maintenance is to adjust the detector sensitivity downward which, in turn, increases the nuisance stimulus needed for alarm. Unfortunately, this has the direct effect of reducing the detector sensitivity to fire as well. A redundant system with more than one detector has been used to address malfunctioning detectors themselves. Two spot detector located side-by-side, or dual sensors in an aspirated system provide redundancy. If an alarm is indicated by only one detector, then a functional check is made by the crew on the other co-located detector. If the non-alarming detector passes the functional check, then it is assumed that the alarming detector is malfunctioning. If the non-alarming detector fails the functional check, then it is assumed that the alarm is a valid indication of fire.

In aircraft applications, certification of a particular detection system includes component evaluation and evaluation of the installed system. The performance of the components and the system as a whole must meet certain criteria in order to be certified as installed in a particular cargo compartment configuration. This methodology differs when compared to the approach taken in building fire protection systems. There, detection systems may be designed for different purposes such as life safety or property protection. In these cases the compliance of detection systems include component evaluation and installation according to standard design methods (i.e., UL 268[17] and NFPA 72[18]). Nuisance alarms are reduced by fine tuning the system after it becomes operational.

2.2 Component Evaluation

Aircraft fire detection components are subject to compliance with standards laid out in FAA Technical Standard Order TSO-C1c, "Cargo Compartment Fire Detection Instruments."[19] This document applies to a minimum performance standard, environmental standard, and computer software verification and validation for equipment designs including analog and digital computer. For new models of fire detection equipment the TSO refers to the standards promulgated by the Society of Automotive Engineers (SAE), Aerospace Standard (AS) Document No. AS 8036, "Cargo Compartment Fire Detection Instruments."[20] Acceptable environmental exposure, and software verification and validation procedures are listed in Radio Technical Commission for Aeronautics (RTCA) Document No. DO-160B. "Environmental Conditions and Test Procedures for Airborne Equipment," and RTCA Document No. DO-178A, "Software Considerations in Airborne Systems and Equipment Certification"[21,22] respectively. Environmental exposure testing and software verification and validation are necessary steps to meeting the criteria of the TSO; discussion of the specifics of those tests is beyond the scope of this paper.

AS 8036 applies to detectors that respond to carbon monoxide or smoke (specifically, smoke detectors that operate on the photo-electric or ionization principle.) The upper bound on the calibration tests for carbon monoxide detectors is specified as 0.020 %; no alarm criterion is specified. Smoke measurements are to be expressed in percent light transmission through a 0.3 m (1.0 ft) path length relative to clean air light transmission. The test chamber (smoke box) described in UL 217[23] or UL 268[17] are stated as the preferred configuration. AS 8036 specifies that the alarm range be set to a level between 60 % to 96 % light transmission; TSO-C1b modifies the alarm range to between 85 % and 96 %.[1]

AS 8036 also establishes minimum requirements for environmental operating conditions. In pressurized areas the instrument shall function over a temperature range of –30 °C to 60 °C, and shall not be adversely affected by exposure from –85 °C to 158 °C. The instrument shall function at relative humidity levels ranging from 0 to 95 %, at altitude pressures from sea level to 15, 240 m, and shall not be adversely affected by pressures between 169 kPa (1270 mm Hg) and 50 kPa (380 mm Hg). In addition, instrument vibration testing requirements are specified. Any fire detection instrument must be ruggedly constructed in order to meet the performance of AS 8036.

The light extinction measures do not specify the type of smoke. If UL 217 were used as the basis for the test bed for the light extinction measures, one would presume that either a black (flaming fuel) smoke or a light colored (smoldering fuel) smoke or both would be prescribed. Since system evaluation universally considers smoldering-like smokes, it seems logical that the component evaluation would be based on light-colored smoke sensitivity. UL 217 and 268 specify operating limits between 87.4 %/m to 99.3 %/m

(96.0 %/ft to 99.8 %/ft) light transmission for gray smoke (smoldering wick test), and between 70.7 %/m to 98.4 %/m (90.0 %/ft to 99.5 %/ft) light transmission for black smoke (smoking kerosene lamp.)

In Europe, the Joint Aircraft Regulation 25.858, is identical to FAR 25.858. Daimler-Chrysler Aerospace Airbus, a supplier in the European market, has developed in-house sensitivity and calibration requirements for photo-electric smoke detectors used on aircraft.[24] The requirements are based on the EN 54 Standard part 7 and part 9.[25] EN 54 part 7 includes provisions for exposing a detector to a paraffin oil aerosol in a wind tunnel. EN 54 part 9 describes a series of test fires and a large room enclosure for testing the sensitivity of ceiling-mounted detectors. For the purposes of aircraft smoke detection, Daimler-Chrysler requires that a detector provide a smoke signal for a light transmission value between 98.0 %/m and 94.0 %/m (99.4 %/ft to 98.1 %/ft.) While this light transmission range is much higher than the range in TSO-C1b, both the aerosol and light source wavelength band differs between the UL Standards and the EN Standard. In addition, aircraft smoke detectors must detect test fires TF2-TF5 in the detector test room described in EN 54 part 9 within the specified ranges for each test fire. Test fires TF2-TF5 consist of the following: TF2- smoldering wood blocks on a hot plate, TF3-smoldering cotton wicks, TF4-flaming polyurethane foam mats, and TF4-heptane pool fire.

2.3 System Evaluation

The FAA requires a demonstration that an installed cargo detection system function properly when exposed to smoke or a simulated smoke source. Typically, testing in only one space is necessary to certify a particular design. Ground testing can use actual burning materials, while flight testing is limited to simulated smoke generators. In-flight smoke generators have included tobacco smoke generators (smoldering tobacco is not considered a fire), theatrical smoke generators, mineral oil smoke generators, and paraffin oil smoke generators. Advisory Circular 25-9A specifies a smoldering fire that produces a small amount of smoke as suitable for demonstrating system performance.[26] The system must detect the fire within one minute from the start as required in FAR 25.858. There is no single standard smoke test; the regional Aircraft Certification Office (ACO) has the authority to specify acceptable smoke generation conditions. Accepted methods do vary according to the specific region in which the testing is done. The FAA Technical Center produced a video of a smoldering suitcase to provide some guidance on what constitutes a reasonable scenario. Questions have been raised by system installers and certifying official about the interpretation of the video. Industry would like to have a standard smoke source that is repeatable and represents realistic conditions. In anticipation of new technologies, sensors, and detection schemes, any change in current certification and evaluation methods should be adaptable to allow for the evaluation of other technologies.

Current aircraft detector evaluation and certification methodologies are limited to smoke detection. In order for new technologies to be considered for aircraft applications, evaluation methods must be developed, fire signatures other than smoke obscuration need to be quantified, and sources that could produce nuisance alarms need to be identified. Evaluation methods could be simple variants of existing methods, or new approaches. The FAA is in the process of developing a standard test or tests for the evaluation of fire detectors in cargo compartments. Quantification of the production rates of smoke, combustion gases, thermal energy (plume temperature), and radiation of the test fire(s) will allow for emulation of realistic fire signatures for cargo compartment testing and could become the basis for certification requirements. Techniques to simulate all relevant fire signatures during in-flight testing need to be developed along the lines of the simulated smoke generators. Nuisance sources depend on the sensing technology, so a comprehensive description of aircraft cargo environments likely to be experienced during the life of an aircraft needs to be developed. New technologies must demonstrate immunity to false alarm that is as good as the current technology. Indeed, they should seek to demonstrate a three-fold improvement in immunity to false alarm just to maintain the number of nuisance alarms per year at a constant level. This suggests a means to test a detector's response to nuisance sources should be available.

2.4 FE/DE Approach

Experimental values or model simulations of smoke concentration, gas concentrations, temperature, and flow velocity can be reproduced in a laboratory setting to examine a specific detector's response over a wider range of conditions. The NIST Fire Emulator/Detector Evaluator was designed specifically for that task. It is suitable for evaluation of spot-type detectors or aspirated systems.

The Fire Emulator/Detector Evaluator (FE/DE) was first introduced by Grosshandler.[27] The concept of the FE/DE is to be able to simulate the conditions of fire and non-fire (nuisance) sources expected in the environment a detector will be placed such that new sensors, detectors, and detection algorithms can be evaluated. The FE/DE is a flow tunnel designed to reproduce the time-varying speed, temperature and concentration (gas and particulate) expected in the fire plume in the early stages of the fire (Figure 1.) The device has a test section 0.3 m high and 0.6 m wide (Figure 2); if an aspiration system is tested, it would draw from this location. The FE/DE employs a variable speed blower and resistance heaters to control velocity and temperature (ambient and higher) over ranges of 0.02 m/s to greater than 1 m/s and 20 °C to 80 °C, respectively. CO, CO_2, and hydrocarbon gases can be added to the flow in a controlled manner. Water vapor is added by evaporation of a mist spray at the outlet of the heater section. A propene diffusion burner smoke generator produces black smoke that may be injected into the tunnel. Smoke concentrations up to 40 %/m obscuration can be achieved. A dust nuisance source is simulated by injecting ISO 12103-1 Arizona test dust.[28] Liquid aerosols are introduced by a nebulizing aerosol generator originally designed for smoke detector testing.[29] Provisions are planned for an additional smoldering fire source, reduced air temperature and controllable detector temperature.

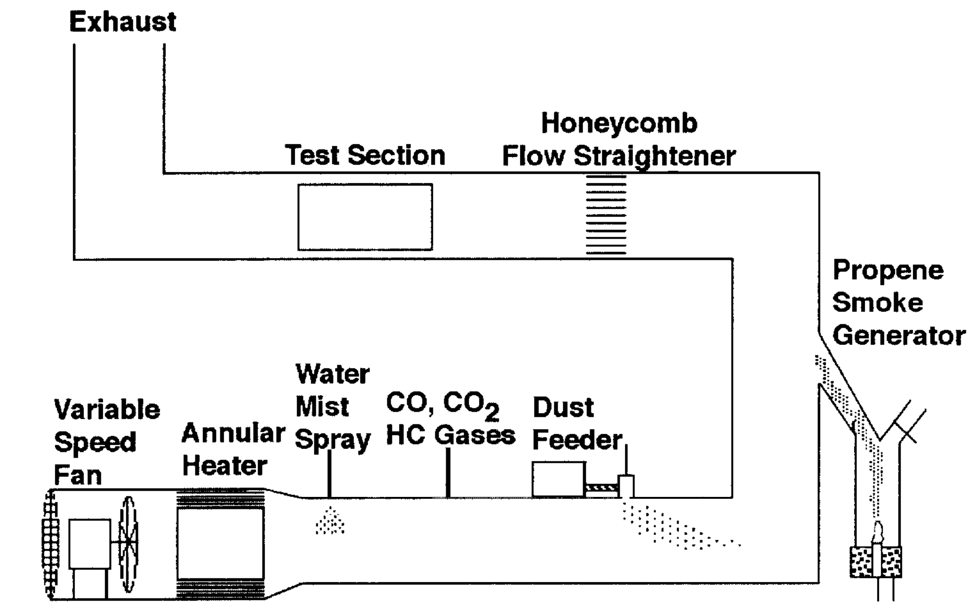

Figure 1. Schematic of the Fire Emulator/Detector Evaluator (FE/DE).

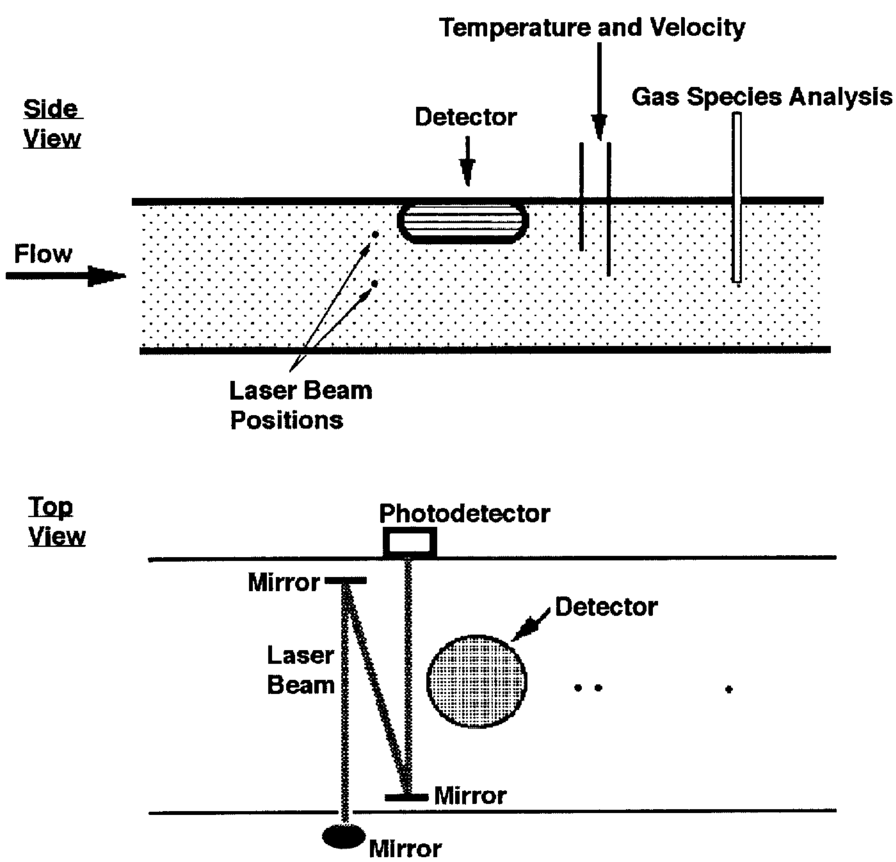

Figure 2. Schematic of FE/DE test section.

2.5 Modeling

Computational Fluid Dynamics (CFD) codes and computer speeds have reached a point where meaningful predictions of fire induced flows can be made. Smoke and heat can be tracked from the fire source distributing throughout a space. CFD model calculations by Davis *et al.* predicted fire-induced flows in a compartment with a sloped, exposed beam ceiling.[30] Detector alarm and sprinkler activation was predicted from the model output and estimation of smoke buildup. Andersson and Holmstedt detail CFD modeling and validation studies of the EN 54 standard test fire room with different fires and the effects of an additional non-fire heat source (radiant heater) located in the room.[31] The CFD calculations would be used as inputs into the FE/DE to assess detector performance for specified simulated scenarios. Cleary *et al.* modeled a standard test fire in an EN 54 room.[32] Model output of the velocity and temperature were used as input to the FE/DE, along with measured values of smoke concentration, to evaluate a multi-sensor/multi-criteria detector.

In aircraft cargo compartment applications, CFD calculations of the fire flows, smoke, and heat transport could be performed to assess the impact of the location of a standard fire, detector positions, the cargo loading level, and background ventilation flows on the time to alarm for a given detector. A CFD model has been applied to aircraft cargo compartment fire detection and suppression simulation under the Fire Detection and Suppression Simulation (FIREDASS) project.[33]

3.0 Fire Detection Technology

Grosshandler has described a number of sensors and technologies for advanced fire detection.[34] The fire detection problem covers a wide range of scenarios from smoldering to flaming combustion, large area protection in industrial settings to very localized detection in electrical cabinets, residential or commercial occupancies. No single solution exists that covers this wide range; solutions are formulated based on likely scenarios for a particular space. Likewise, there are different types of fire detection technologies that have been developed or have been proposed for specific applications. Fire detection technology is constantly evolving as new ideas are proposed and existing technologies are extended. Any survey of state-of-the-art fire detection technology is out of date in a few years. To identify the present and potential near-future status of fire detection, a review of technologies was undertaken. The review consisted of an examination of the scientific literature, patent searches, and a solicitation of ideas in the form of an announcement in the Commerce Business Daily. Interviews with individuals involved with fire research were also conducted.

A review of the scientific literature was conducted to assess the state-of-the-art in fire detection technologies. The NIST Fire Research Information Service (FRIS) library database FIREDOC was queried using the following key words/phrases: fire detection, smoke detectors, aircraft. Based on the contents of each abstract, appropriate documents were retrieved. Most cited documents in this report were retrieved from FRIS.

Patent databases available on the World Wide Web were searched for recent patents pertaining to fire and smoke detection. Relevant patents are listed in the Appendix B. This patent survey is suggestive of the direction and effort being expended in commercialization of detection technologies.

An announcement was placed in the Commerce Business Daily soliciting information on innovative detection products that may prove useful for aircraft cargo compartments, The text of the announcement is given in Appendix A. There were no direct responses to the announcement. This may be due in part to the specificity of the solicitation or a lack of knowledge by the readership of the requirements for aircraft fire detection.

3.1 Particulate Sensing

Smoke detectors sense the aerosol produced from flaming or smoldering combustion. A detector may be located at the sensing location (spot detector) or it may be remote with the smoke drawn through piping to the detector location (aspirated system). A number of techniques may be used to sense the presence of particulates in the air. A detector's response to a given aerosol, whether it be smoke, dust or condensed vapor, depends on the physical properties, size distribution and concentration of the aerosol. Various particulate smoke detectors are described below.

The principle of operation of an ionization detector is described as follows. Two opposing plates are held at a fixed voltage potential. Alpha particles radiating from a source (americium^{241}) interact with air molecules creating charged ions. These ions flow to the oppositely charged plates generating a small current. Smoke particles entering the detector flow between the plates and scavenge ions, decreasing the electrical current. If the current falls below a preset level the detector goes into alarm. A dual chamber design with a separate chamber that is not exposed to smoke allows for correction of the signal strength due to pressure and temperature effects. An ionization detector is particularly suited for detecting a flaming fire which is accompanied by high concentration of small smoke particles.

The photo-electric detector operates on the principle of the attenuation (scattering and absorption) of electromagnetic waves by smoke particles. A light scattering detector operates in the following manner: a light source (typically a light emitting diode in the visible or IR spectrum) produces a collimated beam that extends across the sensing region. A photo-detector is located such that direct light from the source is blocked. The photo-detector views the area the beam traverses at a fixed angle. Smoke particles that enter the detector scatter light, some of which is directed toward the photo-detector. The amount of light reaching the photo-detector, and thus its signal, is proportional to the size of the particles scattering the light, their optical properties, and the number of particles in the sensing volume. A photo-electric light scattering detector is particularly suited for detecting a smoldering fire which is accompanied by relatively large particles which scatter much more light than the small particles produced in flaming combustion. Photo-electric light extinction detectors measure the attenuation of light over the distance between the light source and the detector. Smoke particles scatter and absorb some of the light, reducing the signal strength. Beam extinction detectors typically extend over distances of several meters in order to increase the extinction signal and to provide detection over an area.

Any aerosol (dust, water fog) at a sufficient concentration can cause smoke detectors to alarm. Condensed water vapor on the alpha radiation source can block radiation in ionization detectors. Accumulations of dust, over time, will reduce the sensitivity of smoke detectors. A maintenance interval is required to periodically check the sensitivity or replace dirty units. Aerosol entrance characteristics for spot type detectors must allow for rapid sensing of the external environment.

Photo-electric and ionization detection are the most frequently used in aircraft cargo compartments. In aircraft standards, and indeed, all pertinent smoke detector standards, the threshold alarm value or detector sensitivity setting is specified at a fixed percentage of light obscuration. For a monocromatic light source, the percent obscuration, Obsc., is related to changing light intensity according to the relation

$$Obsc. = 100\left(1-\left(\frac{I}{I_0}\right)^{1/L}\right) \qquad [1]$$

I_0 is the smoke-free light intensity, while I is the intensity when smoke is present. L is the path length (m). The ratio of obscured to un-obscured light depends on the extinction coefficient, k (m^{-1}).

$$\frac{I}{I_0} = \exp^{-kL} \qquad [2]$$

The specific extinction (σ) is the extinction coefficient divided by the smoke mass concentration (C_s; g/m^3), and is the sum of the specific scattering and absorption coefficients (σ_s and σ_a).

$$\sigma = \frac{k}{C_s} = \sigma_s + \sigma_a \qquad [3]$$

Scattering and absorption coefficients for particulate smoke or other aerosols depend on the structure, size distribution and the wavelength-dependent complex index of refraction. Values of specific extinction for smoke produced in flaming fires is typically measured to be 8.5 $m^2/g \pm 1.5$ m^2/g at a wavelength of 633 nm, while for smokes produced from smoldering or pyrolyzing materials the specific extinction is on the order of 3 m^2/g to 4 m^2/g at 633 nm.[35] Absorption can account for 75 % of the extinction for smoke produced from flaming fires, while scattering can account for 80 % or higher of the extinction for smoke produced from smoldering or pyrolyzing material.

A detector that monitors the extinction of a light beam directly correlates with the obscuration measure for the same spectral window. Photo-electric light scattering and ionization detectors operate on different principles. Thus, for flaming and smoldering fires that produce the same obscuration, the signal strength from photo-electric light scattering and ionization detectors is typically not the same.

Mulholland and Liu investigated the response of photo-electric and ionization type detectors to monodisperse aerosols.[36] Figure 3, reproduced from their report, shows the main effect they observed. Larger particles, which scatter more light, produce a higher signal than small particles in a photo-electric light scattering detector. There is a relationship between the scattering angle and the particle size; larger particles tend to scatter more light in the forward direction. An ionization detector experiences a more gradual increase in signal as particle size increases. Qualitatively, the particle number concentration and the particle cross-sectional areas influence the ionization detector output signal.

The time-to-alarm for a detector is a function of the smoke concentration and physical properties of the smoke. The temporal response of a smoke detector is important since it must detect the fire within one minute according to FAR 858. The velocity of the air carrying the smoke to the detector strongly influences the time-to-alarm. The transport of smoke to the sensing volume inside the detector is affected by the flow velocity and the geometry of the detector housing. The time lag of spot-type detectors has been studied, and recently a two parameter model for the smoke entry lag was developed.[37] The model parameters are obtained from smoke detector tests over a range of fixed flow velocities. The model allows for the prediction of smoke entry lag time for fixed or variable velocities. The time response of fan-assisted spot detectors or aspirated systems are less affected by the velocity of the air in the compartment.

Other types of particulate smoke detectors have been proposed. Schmidt-Ott *et al.* developed a smoke detector which senses the residual charge of combustion generated aerosols from either smoldering or flaming combustion.[38] Tests show the device is more sensitive to flaming combustion smoke than it is to smoldering combustion smoke. Non-fire aerosols have a much lower net charge and could be discriminated from the fresh fire-generated particles. Techniques based on multiple scattering angle measurements have been proposed to discriminate smoke from other particulates. Loepfe *et al.* describe a multiple scattering angle measurement technique which can discriminate between smoke, water vapor and other benign particles such as cooking oil aerosols.[39] There is a commercial detector that measures scattering at two angles, 70° and 140°(Caradon Esser GmbH; Nuess, Germany); the ratio of the scattering intensities is used to discriminate between light and dark smokes and nuisance sources such as water vapor.[40] There is a commercial spot detector that uses a fan to draw smoke through a dust filter before it reaches the sensing (photo-electric) chamber.[41] The advantage gained is a reduction in nuisance alarms from sources that produce large particles relative to smoke particles.

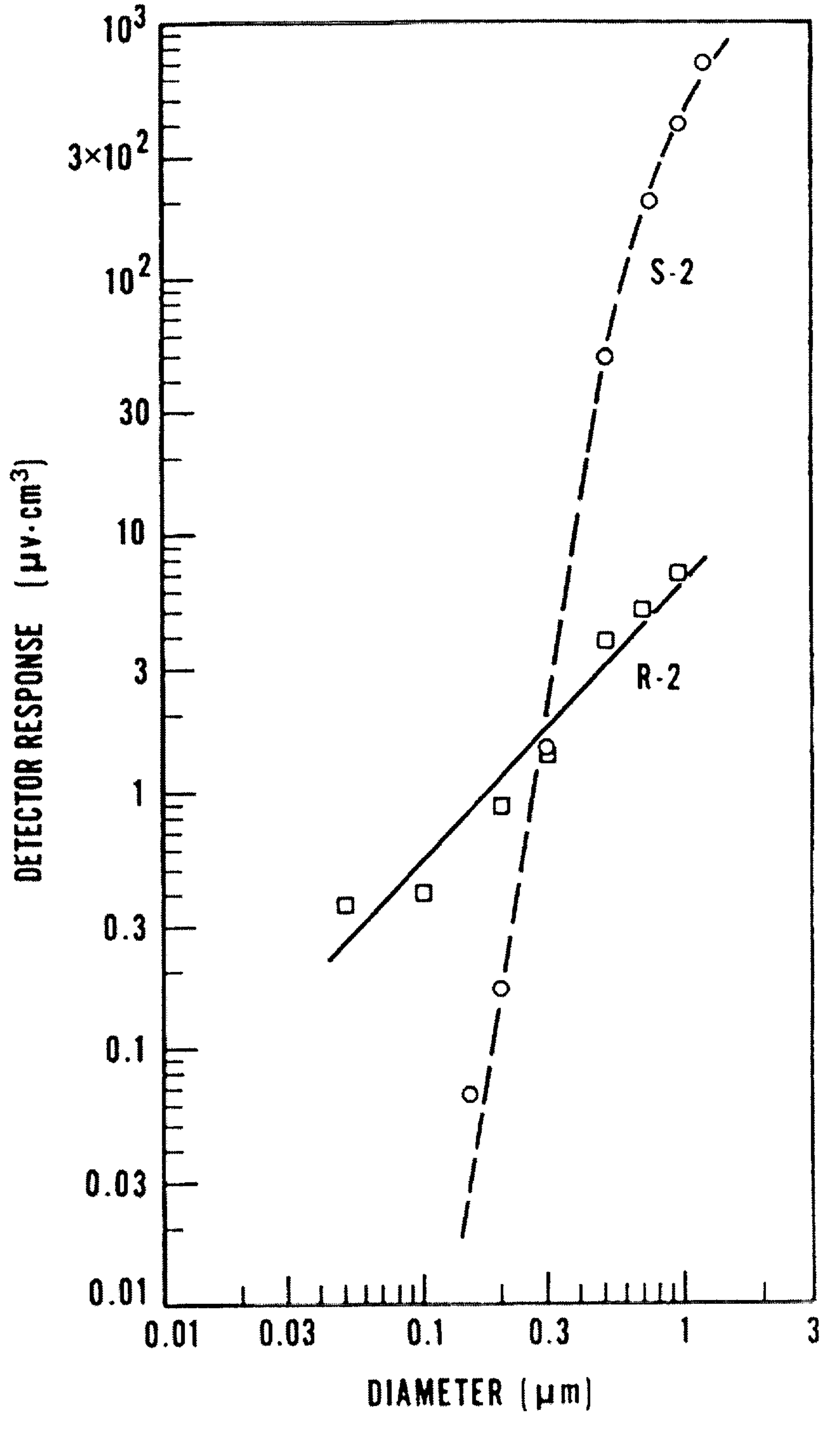

Figure 3. Response of photo-electric (S2) and ionization (R2) smoke sensors to monodisperse aerosols[36].

Litton describes a smoke detector that can discriminate between smoke produced from a fire from the smoke produced from diesel engines.[42] Smoke detectors based on a cloud expansion chamber have been developed.[43] Smoke particles act as nuclei for large droplets formed in the expansion chamber. The droplet concentration is inferred from light extinction or scattering measurements. The presence of fire is indicated when the droplet concentration is high implying a high smoke particle nuclei concentration.

3.2 Thermal Environment Sensing

Thermal energy is convected or radiated away from the fire. Fire can be detected by observing the change in the thermal environment, either through sensing temperature or heat flux rise.

Spot heat detectors that respond to the fire plume temperature, alarming at a fixed temperature or rate of temperature rise, have been used in commercial and industrial fire protection applications. Temperature sensing combined with smoke detection is available from a number of different manufacturers. Line detection with the use of devices such as temperature sensitive resistance wires or pneumatic tubes have been used in aircraft engine nacelles. Fiber optic methods of temperature detection have been commercialized.[44] Since thermal damage to the cargo liner and fire spread and structural damage to the aircraft is a primary concern, temperature detection provides an unambiguous indication of hazard. Relying solely on temperature would be precarious though since smoldering fires may produce low thermal output while growing to a size that could prove hard to control. Combined smoke and thermal detectors that utilize information from both signals have been developed to mitigate concerns with low smoke producing fires.[45]

Heat flux sensors respond to the applied flux incident on the sensing surface. Sensors typically respond to both convected energy and radiant energy. Selectivity between the modes of heat transfer is achieved be reducing the emissivity of the sensor to reduce the radiative energy measured, or by adding windows to reduce convected energy. An experimental study using heat flux microsensors demonstrated that such sensors are capable of detecting fires early.[46]

3.3 Chemical Sensing

Fires produce gaseous combustion byproducts which if they could be sensed would provide a basis for detection. Grosshandler has summarized the chemicals available for early fire detection, including CO_2, H_2O, CO, H_2, total hydrocarbons, and gaseous fuel components.[14] Pfister, Heskasted and Newman, and Gottuck *et al.* investigated the use of chemical sensing to improve fire detection.[47-49] Chemical sensing is seen as potentially beneficial in improving detection and reducing nuisance alarms. Chemical sensing can be achieved by optical spectrographic techniques, catalytic reaction, electrochemical reaction, and mechanico-chemical processes. Sensors based on these techniques are described below.

Optical spectrographic techniques such as Fourier transform infrared spectroscopy (FT-IR) and non-dispersive infrared absorption spectroscopy (NDIR) are possibilities for measuring combustion byproducts. Serio *et al.* have proposed an FT-IR based system for fire detection using a portable "low cost" FT-IR spectrometer.[50] With the FT-IR spectrometer, the absorption spectra over a range of wavelengths is obtained. All IR absorbing gases will produce peaks at various wavelengths. Some intelligence is needed to automatically process the data to determine if fire gases are present. Either an open path or extractive system could be employed. Wong describes a fire detector which combines a photoelectric smoke detector and a NDIR CO_2 gas detector that share a common light source.[51] This detector is compact, making it a candidate for spot-type detector deployment. Nebiker and Pleisch describe a CO_2 gas detector based on photo-acoustic sensing (in principle any IR absorbing gas can be detected).[52] Photo-acoustic gas analyzers are commercially available; this research suggests the technique can be extended to fire detection. The principle of operation is based on the absorption of IR energy by the gas being detected. The light from an IR source is passed through a filter, optically chopped and then passed through a cell that contains the gas to be detected. If the IR wavelength matches the absorption wavelength of the gas to be detected, thermal expansion and contraction produce an acoustic signal that is related to the gas concentration.

Catalytic gas sensors use the heat of reaction of the chemical being sensed as it is oxidized catalytically to quantify concentration. Denney provides a description of these devices.[53] The pellistor type of detector consists of a refractory bead that has an imbedded platinum wire inside. The platinum wire is used to heat up the catalyst bead and is also used as a resistance thermometer. The power requirement necessary to sustain the catalyst temperature depends on the heat liberated from the exothermic reaction of oxidizing species. The platinum wire resistance is part of a wheatstone bridge circuit and the out-of-balance voltage from that circuit is proportional to the gas concentration. Depending on the operation temperature of the bead, and the make-up of the catalyst, some chemical selectivity can be achieved. Hydrogen, carbon monoxide, and hydrocarbon gases can be sensed by catalytic detectors. These types of detectors have limited selectivity, and are susceptible to catalyst poisoning.

Semiconductor gas sensors respond to gas concentration by monitoring change in the electrical conductivity of a semiconductor metal oxide in the presence of the gas being sensed. A common formulation is a tin oxide Taguchi-type sensor. These detectors typically operate at temperatures in excess of 300 °C. Given a mixture of reducing gas and O_2, an equilibrium concentration of oxygen ions and reducing gas will be present on the metal oxide surface. Conductivity is a function of the gas phase concentration which produced the surface equilibrium concentration. Some selectivity is achieved through doping with noble metals and special preparations. Tournier *et al.* describe CO and CH_4 gas sensors using tin oxide doped with palladium.[54] CO detection at near ambient temperatures is claimed. Harwood *et al.* describe a platinum doped tin oxide sensor for CO that operates at low power consumption.[55] Semancik and Whetstone describe a planar array of thin film microsensors deposited on a temperature controlled micro-hotplate.[56] Power requirements are lower than conventional semiconductor gas sensors.

The benefit of an array of sensors is realized by adjusting the selectivity of each sensor and processing the individual sensor signals together to reduce cross-sensitivity among different gases.

Electrochemical sensors of various designs exist. Measurement of the change in current, voltage, or conductance due to electrochemical reactions with the gas species of interest is the basis of these sensors. Potentiometric solid-state electrochemical sensors have been constructed for O_2, H_2, H_2O, CO, and CO_2.[34] Penney describes a research program to assess the effectiveness of an electrochemical CO sensor as the basis for a fire detector.[57] Power consumption and response time were found to be adequate, and a CO fire detector was deemed feasible.

Mechanico-chemical sensors consisting of organic thin films deposited on crystal surfaces could potentially sense a fire.[34] The frequency of surface acoustic waves (SAW) is affected by chemical species that diffuse through the organic membrane. Selectivity is achieved by tailoring the polymer coating. Hierlemann *et al.* describe a six sensor array designed to detect organic vapors.[58]

3.4 Radiation Sensing

Flaming fires emit radiation over a broad band of wavelengths. Ultraviolet (UV), visible, and infrared (IR) emissions can be detected from many flames. Radiation emission has been used in detection schemes; ultraviolet, visible and infrared emission has been used separately and in various combinations. In general, a radiation detector must be within the line-of sight of the fire or its reflected image.

Ultraviolet, UV/IR, and dual IR band sensors are typically used to detect flaming fires that may occur in open spaces. UV/IR and dual IR band detectors have been developed that reject common interfering signals such as reflected solar radiation and welding operations. Tapphorn *et al.* describe an infrared fiber-optic fire sensor.[59] A centralized detector receives IR radiation directed by the optical fiber. Fibers that have good transmission in the 1 to 5 μm wavelength region were identified and used.

One device that does not need an unobstructed view is the near infrared fire detector described by Lloyd *et al.*[60] Spectral radiation intensities at 900 nm and 1000 nm wavelengths incident on the detector are sampled at 500 Hz. By analyzing the time series data an algorithm that can discriminate fires through frequency and radiant power characteristics was proposed. It was demonstrated that even without a direct line of sight, radiation that was reflected off a wall was sufficient to detect a fire. Reflected radiation from smoldering fires was below the detection limit and a non-luminous alcohol fueled fire could not be detected. Near infrared radiation can be transmitted by optical fibers, allowing for increased coverage by multiplexing signals from separate optical fibers.

Koseki *et al.* describe a multi-spectrum video system that records images in the UV, visible and near infrared simultaneously.[61] Image processing for of the three views is suggested as a means to detect a variety of fires. A video-based machine vision fire and smoke detection device has been proposed and testing in a military aircraft cargo compartment was performed.[62] Videos were captured and the individual red, blue and green components of the images were analyzed to indicate the presence of fire or smoke in the field of view. Smoke detection requires a light source located away from the camera. The use of fiber optics to increase the coverage of a single camera was discussed.

3.5 Signal Processing

Many of the sensors described above are of little or no use without proper signal processing of the sensor output. Likewise, multi-sensor detectors benefit significantly from appropriate processing of the separate detector signals. Proposed machine vision or other imaging fire detection systems, FT-IR spectrographic, or sensor array systems need to process the information to decide if a fire is present. Detector manufacturers are developing individual spot-type detectors that include all of the signal processing on the circuit board of the detector itself. Each detector can include a central processing unit (CPU), software storage in read only memory (ROM), random access memory for time series data storage and analog to digital (A/D) converters. The detector can pass information to a central panel when it is polled or it senses a fire.

Pfister describes several applications of multi-sensor/multi-criteria fire detectors that outperform single sensor detectors.[63] Some of the common signal processing techniques proposed or now in use in fire detection systems are presented below.

A fixed signal threshold value for a sensor represents the simplest and most common use of fire sensor output. Automatic compensation for baseline drift due to aging or environmental effects can maintain a threshold level criterion for a detector. Filtering or time averaging the sensor signal can be used to suppress spurious signals due to electromagnetic interference and short term environmental changes. The rate of change, or frequency of a fluctuating signal may contain useful information for discriminating fire and non-fire stimuli.

Klose and Siebel discuss the use of the auto-correlation function of a sensor signal or multi-sensor signals to reduce false alarms.[64] The auto-correlation function is a higher order statistic of a sensor's time series output. For multi-sensor signal processing, assignment of weighting functions to individual signals was suggested as a means to tune detection to specific applications (i.e., most likely fire scenarios.)

Heskestad and Newman demonstrated the use of cross-correlation of time averaged sensor signals in fire detection.[48] They measured the CO, CO_2, and total hydrocarbons concentration, ionization detector output, light scattering detector output, optical density measurements at different wavelengths, and temperature signals generated in a series of test fires. They examined a number of double and triple correlations. They found two complementary cross-correlations: CO concentration correlated with ionization detector output, and CO_2 concentration correlated with temperature. These two cross correlations could detect all test fires used in EN 54 part 9 much earlier than individual detector classification times.

Gottuck *et al.* examined multi-signature alarm algorithms using the output from smoke detectors (photo-electric and ionization), CO measurements and CO_2 measurements.[49] They concluded that the combination CO and smoke detector signals using the appropriate algorithm will respond to real fires faster than a smoke detector alone, and additionally, will reject many nuisance source alarms. A robust combination identified was a CO sensor and an ionization smoke detector.

Ishii and Yamauchi describe an algorithm that uses temperature, CO, and smoke signals presented in a three dimensional coordinate system with several threshold planes defined.[65] The threshold planes map certain CO-temperature-smoke volumes where fire would be expected if the sensor values fall within.

Thuillard describes fuzzy logic and its application to fire detection, and goes on to apply fuzzy logic to an ionization detector output.[66] Fuzzy logic is particularly suited to combining two or more different signals in a decision algorithm. Fuzzy logic allows for more flexibility than classical logic; thus more complex phenomena can be analyzed. Hosokawa *et al.* describe a three sensor (smoke, heat, and CO) fire detector that uses fuzzy logic to discriminate fire from false alarm sources.[67]

Okayama describes an odor sensor made from two tin oxide (Taguchi-type) sensors with different response characteristics, utilizing an artificial neural network trained to distinguish fire from environmental odors.[68] A neural net is a computational scheme that seeks to mimic the decision making process of the brain. The odor sensor must be trained by exposure to different sources, and the extent of training affects the performance of the neural net. Okayama *et al.* designed a neural net that uses the odor sensor in combination with a smoke sensor.[69] Ishii *et al.* designed a neural net that utilizes data from temperature, smoke, and CO gas (semiconductor type) sensors.[70]

Milke and McAvoy investigated the feasibility of a six sensor fire detector that uses a neural net to discriminate between flaming fire, non-flaming fire and nuisance sources.[71] The sensors considered consist of light obscuration, temperature, CO, CO_2, and two Taguchi-type tin oxide sensors. The arrangement appears to provide earlier detection compared to commercial fire detectors.

Chen *et al.* describe a fire detection system that employs an FT-IR spectrometer and processes the data in an artificial neural network.[72] It was concluded that the device has the ability to distinguish between non-fire, and fire sources as well as the mode of combustion (smoldering or flaming).

Siebel describes an alternative fire detection concept, the "no-fire-detector".[73] The detector estimates whether the observed conditions belongs to normal ambient conditions. An alarm is initiated only when the observed conditions are extremely unlikely. The detector continuously collects data and updates parameters relating to statistical probability densities of observed signals. Thus after installation, the detector will automatically adjust parameters to represent the normal ambient conditions it experiences. Parameters from detectors in similar installations could be imported as the base parameters for new installations. The concept was tested against data from ionization, photo-electric light scattering and temperature sensors, that was collected in various installations over a period of several years. The results show that single sensor fire detectors could significantly decrease nuisance alarms by learning about the environment and adjusting to it.

A NIST experimental study for the Consumer Product Safety Commission examined various sensor signals in the vicinity of cooking ranges.[74] The objective of the study was to determine if sensors could provide an indication of imminent ignition of the contents of cookware during unattended cooking, and thus provide a signal for automatic range-top power cutoff. For the various cooking activities, cookware, and ranges examined, no single sensor provided pre-fire signals without a significant factor of false alarms. A combination of a range-top thermocouple and a gas sensor in the form of the product of the two signals provided discrimination between cooking activities and imminent fire conditions almost perfectly for the cases studied.

4.0 SUMMARY AND RECOMMENDATIONS

Detector evaluation and system certification for aircraft cargo compartment applications have been summarized. The standards and methods used are almost universally specific to smoke detection. The desire for a uniform smoke source to perform certification testing has been expressed by industry. Evaluation of detectors based on technologies other than standard smoke detection will present challenges. The NIST FE/DE is being modified to produce fire signatures and nuisance signatures characteristic of more realistic cargo compartment environments. In conjunction with experimental and modeling results of the detector environment, the FE/DE could prove a useful tool for evaluating new spot or aspiration-type detectors.

New sensor technologies and signal processing techniques show promise in increasing cargo compartment detection system sensitivity while discriminating nuisance sources. Table 1 lists some of the strengths and weaknesses of the technologies described above as they relate to cargo compartment detection. It is important to stress the reasons for considering any new technology for aircraft cargo compartment fire detection. The application of a new technology should be accompanied by attaining desired goals. Suitable goals related to cargo compartment fire detection include the following:

1. Faster detection of real fire threats

2. Better nuisance source discrimination

3. Improved reliability

4. Enhanced indication of hazard level

The first three goals stand on their own merits. The fourth goal presupposes such information would be useful to decision makers (the crew or as feedback to automatic suppression systems). The assessment of the level of improvement for the first three goals is a difficult task. There is a need for testing and evaluating protocols to address the expected level of achievement of such goals prior to fielding technologies.

All of the listed technologies, or variants thereof, could presumably be used for cargo compartment fire detection applications. There are constraints that impact the suitability of implementing any technology including the following:

1. Cost; cost-effective solutions (including installation and maintenance) are the only ones which will likely be considered.

2. Operational constraints, including: temperature, pressure, humidity, and vibration conditions.

These goals and constraints define the information needed for assessment of suitability. The importance of each goal is based on value judgements of the benefits derived from a technology change. Considering the first three goals as equally important, solutions that could be implemented in the near term are suggested below:

- Improving photo-electric or ionization-type detector performance by implementing advanced signal processing algorithms to reduce spurious signals that are not the product of smoke in the sensing chamber.

- Using a multi-sensor detector to discriminate nuisance sources from fire events. It is possible that as few as two properly chosen sensors could be used to discriminate the most likely nuisance sources experienced in cargo compartments.

For instance, combining the output from a smoke sensor and a chemical sensor such as CO or CO_2 could possibly be robust and immune to typical nuisance sources that cause smoke-only detectors to alarm. Adding a thermal sensor could aid in the detection of rapidly growing, flaming fires and provides an indication of the hazard level in the cargo compartment. The Airline Pilots Association has taken a position that a thermal sensor should be installed in inaccessible cargo compartments to provide an indication of the imminent hazard.[75] Detailed information on the nuisance source levels that affect current detectors and the fire signatures of cargo compartment fires are needed to select appropriate sensor combinations.

Table 1. Fire Detection Technology for Cargo Compartments

Technology	Strengths	Weaknesses
Particulate Photo-electric Ionization Cloud Chamber	Good sensitivity Highly engineered and robust. Ability to discriminate between fire aerosol and environmental dust levels.	Susceptible to nuisance sources such as dust, aerosol sprays and condensed moisture. For non-fan assisted spot detectors, smoke transport to the sensor affects performance. Current nuisance alarm rate poor. Complex machinery, reliability issues
Thermal Thermocouple, RTD Line Detector Fiber Optic Heat Flux	Temperature measures may indicate fire threat	Low energy output smoldering fires maybe difficult to detect. Need to protect sensors from mechanical damage.
Chemical FTIR NDIR Photo-acoustic Catalytic Semiconductor Electrochemical Cell	Levels of certain chemical species and ratios of chemical species produced from fires are distinct and indicative of fire events.	Long-term reliability, poisoning, cross-sensitivity to environmental gases, size and cost constraints for complex systems. Limited sensor operating life.
Radiation Ultraviolet, Infrared Video Based Methods	Very fast. No transport delays, volumetric coverage.	Smoldering fire difficult or impossible to detect. Unobstructed line-of-sight to fire or strong reflection needed.
Signal Processing	Maximization of sensor data. Noise and spurious signal filtering.	Sensor and application specific algorithms. Research needed to develop effective solutions.

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5.0 REFERENCES

1. Blake, D. R., "Suppression and Control of Class C Cargo and Compartment Fires, Final Report," August 1983-June 1984, DOT/FAA/CT-84/21, p. 31, Federal Aviation Administration, Atlantic City, NJ, February 1985.
2. Grosshandler, W. L. (editor), "Nuisance Alarms in Aircraft Cargo Areas and Critical Telecommunications Systems: Proceedings of the Third NIST Fire Detector Workshop", December 4-5, 1997, NISTIR 6146, National Institute of Standards and Technology, Gaithersburg, MD, March 1998.
3. Blake, D.R., Private communication, April, 1999.
4. "Revised Standards for Cargo or Baggage Compartments in Transport Category Airplanes," Notice of Proposed Rulemaking (NPRM) No. 97-10, Federal Aviation Administration, Department of Transportation, 1997.
5. Federal Aviation Regulations 25.858, "Cargo or Baggage Compartment Smoke or Fire Detection Systems."
6. Federal Aviation Regulations 25.857, "Cargo Compartment Classification."
7. Blake, D. R., and Hill, R. G., "Fire Containment Characteristics of Aircraft Class D Cargo Compartments, Final Report," DOT/FAA/CT-82/156, p. 40, Federal Aviation Admin., Atlantic City Airport, NJ, June 1983.
8. Amendment 25-60, 51 FR 18236, May 16, 1986
9. Amendment 25-63 FR 8032 No. 31, Feb 17, 1998.
10. Nurcombe, C. and Carver, M., "A330/A340 Cargo Bay Condensation and Smoke Warnings Solutions Available," *FAST Airbus Technical Digest*, Number 21, May 1997.
11. Blake, D.R., Private Communication, May, 1998.
12. Blake, David R., "Fire Hazards of Aerosol Cans in Aircraft Cargo Compartments. Final Report," DOT/FAA/CT-89/32, 21 p., Federal Aviation Administration, Atlantic City, NJ, December 1989.
13. Jackson , M. A., and Robins, I., "Gas Sensing for Fire Detection: Measurement of CO, CO2, H2, 02, and Smoke Density in European Standard Fire Tests," *Fire Safety Journal* 22, pp. 181-205, 1994.
14. Grosshandler W.L., "A Review of Measurements and Candidate Signatures for Early Fire Detection," NISTIR 5555, National Institute of Standards and Technology, Gaithersburg , MD, January, 1995.
15. Cleary, T., Grosshandler, W., Nyden, M., and Rinkinen, W., " Signatures of Smoldering/Pyrolyzing Fires for Multi-Element Detector Evaluation", Proceedings of the 7th Inter. Conf. On Fire Science and Eng., *Interflam '96*, Cambridge, England, March 1996.
16. Blake, D.R., Private Communication, May, 1998.
17. *UL 268: Standard for Smoke Detectors for Fire Protective Signaling Systems*,Underwriters Laboratories, Inc., Northbrook IL, 1989.
18. NFPA 72E, *Standard on Automatic Fire Detectors, National Fire Protection Association*, Quincy, MA, 1984

19. Technical Standard Order TSO-C1c, "Cargo Compartment Fire Detection Instruments," DOT, FAA, Aircraft Certification Service, Washington, DC, 1987.
20. "Cargo Compartment Fire Detection Instruments," *Aerospace Standard*, AS 8036, Society of Automotive Engineers, Inc., Warrendale, PA, 1985.
21. "Environmental Conditions and Test Procedures for Airborne Equipment," Radio Technical Commission for Aeronautics (RTCA) DO-160B, 1984
22. "Software Considerations in Airborne Systems and Equipment Certification", Radio Technical Commission for Aeronautics (RTCA) DO-178A, 1985
23. *UL 217: Standard for Single and Multiple Station Smoke Detectors*, Underwriters Laboratories, Inc., Northbrook IL, 1993.
24. Schmotzer, K., Private Communication, April, 1999.
25. *EN 54: Components of Automatic Fire Detection Systems*, European Committee for Standardization, Part 9, 10 p., July 1982.
26. Advisory Circular, AC 25-9A, "Smoke Detection, Penetration, and Evacuation Tests and Related Flight Manual Procedures," DOT, FAA.
27. Grosshandler, W., "Towards the Development of a Universal Fire Emulator-Detector Evaluator," *Fire Safety Journal*, 29, pp. 113-128, 1997
28. Powder Technology Incorporated, P.O Box 1464 Burnsville, MN 55337.
29. Lee, T. G. K., "Instrument to Evaluate Installed Smoke Detectors. Final Report," NBSIR 78-1430, National Bureau of Standards, Gaithersburg, MD, February 1978.
30. Davis, W., Forney, G., and Bukowski, R., "Developing Detector Siting Rules from Computational Experiments in Spaces with Complex Geometries," *Fire Safety Journal*, 29, pp 129-139, 1997.
31. Andersson, P., and Holmstedt, G., "CFD-Modelling Applied to Fire Detection – Validation Studies and Influence of Background Heating," *International Conference on Automatic Fire Detection "AUBE '95", 10th*, April 4-6, 1995, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 429-438, 1995.
32. Cleary, T., Anderson, M., Averill, J., and Grosshandler, W., "Evaluating Multi-Sensor Fire Detectors in the Fire Emulator/Detector Evaluator," Proceedings of the 8th Inter. Conf. On Fire Science and Eng., *Interflam '99*, Edinburg, Scotland, June 1999.
33. Grandison, A., Mawhinney, R., Galea, E., Patel, M., Keramida, E., Boudouvis, A., and Markatos, N., "The FIREDASS Model," Int. Aircraft Fire and Cabin Safety Research Conference, Atlantic City, NJ, 1998.
34. Grosshandler, W. L., "An Assessment of Technologies for Advanced Fire Detection," *Heat and Mass Transfer in Fire and Combustion Systems*, ASME HTD-Vol. 223, pp. 1-10, Dec. 1992.
35. Mulholland, G.W., "The Emission and Optical Properties of Smoke," Recent Advances in Flame Retardancy of Poymeric Materials, Vol III, Ed., Menachem Lewin, Proceedings of the 1992 Conference, BCC Inc., 1992
36. Mulholland, G., and Liu, B., "Response of Smoke Detectors to Monodisperse Aerosols," *Journal of Research of the National Bureau of Standards*, Vol 85, No. 3, May-June, 1980.

37. Cleary, T., Chernovsky, A., Anderson, M, and Grosshandler, W., "Particulate Entry Lag for Spot Type Smoke Detectors," *6th International Symposium,, Intl. Assoc. for Fire Safety Science*, 1999.
38. Schmidt-Ott, A., Krull, W., and Burtscher, Hl, "Electrostatic Fire Detector," 9th International Conference on Automatic Fire Detection, AUBE '89, pp. 215-227, H. Luck ed., Duisburg Germany, 1989..
39. Loepfe, M., Ryser, P., Tompkin, C., and Wieser, D., "Optical Properties of Fire and Non-Fire Aerosols," *Fire Safety Journal*, Vol. 29, No. 2/3, pp. 185-194, September/October 1997.
40. Dual Fire Detector, Caradon Eser GmbH, Dieselstrabe 2 41466 Neuss Germany.
41. Bellavia,N.J., "Detection in Difficult Environments," *International Conference on Automatic Fire Detection "AUBE '99", 11th*, March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 213-218, 1999.
42. Litton, C., "Diesel-Discriminating Fire Sensor," Bureau of Mines IC 9206, pp. 28-32, 1988.
43. Bukowski, R., and O'Laughlin, R., "Fire Alarm Signaling Systems," Second Edition, National Fire Protection Association, Inc., 1994.
44. Notz, R., "New Fire Detection Concepts with Fiber Optics Tehcnology," *International Conference on Automatic Fire Detection "AUBE '99", 11th*, March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 303-312, 1999.
45. Wang, L., Zhu, C., and Wang, J., "A New Type of Intelligent Point Photoelectric Smoke-Heat Combined Fire Detector," *International Conference on Automatic Fire Detection "AUBE '99", 11th*, March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 262-271, 1999.
46. Lattimer, B., Langley, L., and Vandsburger, U., "Detecting Fires Using a Thin-Film Heat Flux Microsensor," HTD Vol. 296, Fire, Combustion and Hazardous Waste Processing, ASME, 1994.
47. Pfister, G., "Detection of Smoke Gases by Solid State Sensors – A Focus on Research Activities," *Fire Safety Journal*, 6 pp. 165-174, 1983.
48. Heskestad, G., and Newman, J. S., "Fire Detection Using Cross-Correlations of Sensor Signals," *Fire Safety Journal*, Vol. 18, No. 4, 355-374, 1992.
49. Gottuk, D.T., Peatross, M.J., Roby, R.J., and Beyler, C.L., "Advanced Fire Detection Using Multi-signature Alarm Algorithms," *International Conference on Automatic Fire Detection "AUBE '99", 11th*, March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 237-246, 1999.
50. Serio, M. A., Bonanno, A. S., Knight, K. S., and Newman, J. S., "FT-IR Based System for Fire Detection," NISTIR 5499, September 1994.
51. Wong, J.Y., U.S. Patent 5,691,704, Nov. 25, 1997.
52. Nebiker,P., W., and Pleisch, R., E., "Photoacoustic Gas Detection for Fire Warning," *International Conference on Automatic Fire Detection "AUBE '99", 11th*, March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 67-76, 1999.
53. Denney, E. J., "Catalytic Detectors for Flammable Gases," *Fire Prevention*, No. 153, pp. 21-26, October 1982.

54. Tournier, G., Pijolat, C., Lalauze, R., Patissier, B., "Selective Detection of CO and CH/4 with Gas Sensors Using Sn)//2 Doped with Palladium," *Sensors and Actuators*, B 26, p 24-28, 1995.

55. Harwood, J. A., Moseley, P. T., Peat, R., and Reynolds, C. A., "Use of Low Power Carbon Monoxide Sensors to Provide Early Warning of Fire," *Fire Safety Journal*, Vol. 17, No. 6, 431-443, 1991.

56. Semancik, S., and Whetstone, J.R., "NIST Programs and Facilities in Gas Sensing and Related Areas," NIST Workshop on Gas Sensors: Strategies for Future Technologies, NIST Special Publication 865, S. Semancik, ed., December 1994.

57. Penney, S., "Development of a New Fire Detection Technology," *International Conference on Automatic Fire Detection "AUBE '99", 11th*, March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 458-467, 1999.

58. Hierlemann, A., Weimar, U., Kraus, G., Schweizer-Berberich, M., and Goepel, W., "Polymer-based Sensor Arrays and Multicomponent Analysis for the Detection of Hazardous Organic Vapours in the Environment," *Sensors and Actuators,* B 26, p 126-134, 1995.

59. Taphorn, R., Kays, R., and Porter, A., "Infrared-Fiber-Optic Fire Sensor Developments: Role of Measurement Uncertainty in Evaluation of Background Limited Range," Proceedings of the ISA Aerospace Instrumentation Symposium, Vol. 35. May 1-4, 1989, Orlando, FL, ISA Services, Inc., Research Triangle Park, NC, 553-565 pp, 1989.

60. Lloyd, A. C., Zhu, Y. J., Tseng, L. K., Gore, J. P., and Sivanthanu, Y. R., "Fire Detection Using Reflected Near Infrared Radiation and Source Temperature Discrimination," NIST-GCR-98-747, National Institute of Standards and Technology, Gaithersburg, MD, April 1998.

61. Kozeki, D., "Observation of Early Stage Fires by a Multi Spectrum Camera," *International Conference on Automatic Fire Detection "AUBE '99", 11th*, March 16-18, 1999, Gerhard Mercator University, Duisburg, Germany, Luck, H., Editor, pp. 180-186, 1999.

62. Goedeke, A.D., "Cost Effective Multi-Purpose Machine Vision Based Fire, Smoke, and Engine Overheat Detectors," Final Report, AFRL/VANS, Air Force Contract No. F33615-95-C-3407, Feb., 1998.

63. Pfister, G., "Multisensor/Multicriteria Fire Detection: A New Trend Rapidly Becomes State of the Art." *Fire Technology*, Vol 33, No. 2, National Fire Protection Association, May/June, 1997.

64. Klose, J., and Siebel, R., "A Fire Detection Algorithm Using Second Order Statistics," *3rd International Symposium, Intl. Assoc. for Fire Safety Science*, Boston, MA, Cox G., and Langford, B., eds., pp. 943-953, 1991.

65. Ishii, H., and Yamauchi, Y., "An Algorithm for Improving the Reliability of Detection with Processing of Multiple Sensors, Signal," *International Conference on Automatic Fire Detection "AUBE '89",*

66 Thuillard, M., "New Methods for Reducing the Number of False Alarms in Fire Detection Systems," *Fire Technology*, Vol. 30, No. 2, 250-268, Second Quarter 1994.

67. Hosokawa, M., Satoh, K., Kouzeki, D., Tamura, H., Okuda, Y., Kusanagi, S., Fujioka, T., Watabe, Y., Kurio, T., and Nakanishi, S., "Study of Fuzzy-Reasoning Intelligent Fire Detection System," U.S./Japan Government Cooperative Program on Natural Resources (UJNR). Fire Research and Safety. 12th Joint Panel Meeting. October 27-November 2, 1992.

68. Okayama, Y., "Approach to Detection of Fires in Their Very Early Stage by Odor Sensors and Neral Net," *3rd International Symposium, Intl. Assoc. for Fire Safety Science*, Boston, MA, Cox G., and Langford, B., eds., pp. 955-964, 1991.

69. Okayama, Y., Ito, T., and Sasaki, T., "Design of Neural Net to Detect Early Stage of Fire and Evaluation by Using Real Sensors' Data," *4th International Symposium, Intl. Assoc. for Fire Safety Science*, Boston, MA, Kashiwagi, T., Editor, pp. 751-759, 1994.

70. Ishii, H., Ono, T., Yamauchi, Y., and Ohtani, S., "Algorithm for Improving the Reliability of Detection With Processing of Multiple Sensors Signal," Nihon Univ., Tokyo, Japan, Hochiki Corp., Tokyo, Japan, *Fire Safety Journal*, Vol. 17, No. 6, 469-484, 1991.

71. Milke, J., and McAvoy, T., "Analysis of Fire and Non-Fire Signatures for Discriminating Fire Detection," *5th International Symposium, Intl. Assoc. for Fire Safety Science*, Melbourne, Australia, Hasemi, Y., Editor, March 3-7, 1997.

72. Chen, Y., Sathyamoorthy, S., and Serio, M., "A New Fire Detection System Using FT-IR Spectroscopy and Artificail Neural Networks," Annual Conference on Fire Research, Building and Fire Research Laboratory, NIST, Gaithersburg, MD, K. Beall Editor, Nov. 2-5, 1998.

73. Siebel, R., "the 'No-Fire-Detector' – An Alternative Fire Detection Concept?" *Fire Safety Journal,* 29, pp. 159-171, 1997.

74. Johnsson, E.L., "Study of Technology for Detecting Pre-Ignition Conditions of Cooking-Related Fires Associated with Electric and Gas Ranges and Cooktops, Final Report", NIST IR 5950, National Institute of Standards and Technology, Gaithersburg, MD, 119 p., January, 1998.

75. Phillips, T., "Cabin and Fire Safety: A Perspective From the Cockpit", Int. Aircraft Fire and Cabin Safety Research Conference, Atlantic City, NJ, Nov. 1998.

Appendix A: CBD Announcement

Proposed changes in the regulations governing commercial aircraft could lead to a significant increase in the number of active fire protection systems required for inaccessible cargo compartments. The current industry standards for detecting the presence of a fire rely on the sensing of smoke particles with either ionization or photoelectric-type detectors. The quantity and method of generating smoke to show compliance with the regulations is not precisely defined and there are no guidelines for detecting fires by means other than smoke detectors. The technologies currently used are susceptible to alarming in the presence of natural aerosols and airborne contaminants other than smoke particles. With the number of aircraft using this technology likely to increase substantially, the number of incidents of unnecessary aircraft diversions and evacuations due to false alarms could be expected to increase proportionally if no improvements are made to the technologies or the methods of system certification.

The National Institute of Standards and Technology (NIST), under a contract from the Federal Aviation Administration (FAA), is conducting a search for existing and emerging fire detection technologies designed for a variety of industries, including commercial aircraft, military, marine, nuclear and manufacturing. It is also assembling and evaluating fire detection certification methods adopted by civilian and military organizations throughout the world. Companies with innovative sensing and fire detection systems commercially available or under development are invited to send in technical information describing their products, and to explain why they may be particularly suited to aircraft cargo area applications. Companies who manufacture equipment useful for certifying fire detection equipment are also invited to respond. The information should include a technical description of the principles of operation and test results as evidence that the system could function in an aircraft cargo hold. Proprietary information, if included, must be clearly marked on every page. Advertisements and marketing literature are not solicited and will be disregarded. To be included in the review process, relevant material must be received at the following address no later than September 21, 1998:

Building and Fire Research Laboratory
Bldg. 224, Rm. B356
Attn. Thomas Cleary
National Institute of Standards and Technology
Gaithersburg, MD 20899

e-mail: thomas.cleary@nist.gov

This solicitation is for information only and does not obligate NIST nor the FAA to purchase, endorse, evaluate, nor make reference to any particular companies' products or technology.

APPENDIX B: RECENT U.S. PATENTS

Particulate Sensing

Optical smoke detector
United States Patent 4,258,360
Inventor(s) Tagashira, Hiroshi
Assignee Nittan Company, Limited
Issued: 1981 03 24 Filed: 1978 07 31

Abstract

An optical smoke detector which includes a light source and light sensing element so arranged that the quantity of light detected by the element will be determined by the presence of smoke in the detector, a power source for periodically supplying sets of actuating pulses to the light source, apparatus connected with the light sensing element for detecting light pulses which are synchronized with the actuating pulses and producing an alarm when pulses of a predetermined magnitude are detected.

Smoke detector having variable level sensitivity
United States Patent 4,792,797
Inventor(s) Tanguay, William P.; McCrink, James
State/Country IL
Assignee Seatt Corporation
Issued: 1988 12 20 Filed: 1987 03 05

Abstract

A smoke detector having variable sensitivity to smoke levels and using one button both to test the smoke detector and actuate a mode of diminished sensitivity to smoke levels. The smoke detector is operable in a normal sensitivity mode and a diminished sensitivity mode with rapid switching between the modes. The sensitivity to smoke levels is substantially constant when in either the normal or diminished sensitivity mode.

Smoke detector
United States Patent 4,321,595
Inventor(s) Tresch, Erwin
Assignee Cerberus AG
Issued: 1982 03 23 Filed: 1979 12 19

Abstract

A smoke detector containing a radiation source operating in a pulsed mode and a scattered radiation receiver connected in a coincidence circuit. This circuit contains a counter which counts both the radiation pulses and the incoming scattered radiation pulses. With undisturbed operation this counter, following each radiation pulse, has an even numbered counter state. The appearance of an uneven numbered counter state is indicative of the presence of spurious pulses and leads to resetting of the counter to null, so that there is prevented attainment of a counter state adequate for tripping an alarm signal. On the other hand, with the presence of a predetermined even numbered counter state there is triggered an alarm. Such smoke detector is almost immune to spurious pulses and does not tend to trigger faulty alarm signals.

Optical smoke detector with contamination detection circuitry
United States Patent 4,555,634
Inventor(s) Muggli, Jurg; Guttinger, Heinz; Horvath, Zoltan
Assignee Cerberus AG
Issued: 1985 11 26 Filed: 1982 11 03

Abstract

A smoke detector is disclosed having a radiation source operated in a pulsed mode. Externally of a direct radiation region of the radiation source there is arranged a radiation receiver which, in the presence of smoke or other particles emanating from a combustion process and located in the radiation region, is impinged by scattered radiation and delivers an output signal to an evaluation circuit. The evaluation circuit contains switching elements which, when the number of source output signals or pulses exceeds a predetermined threshold value for the number of source output pulses, delivers an alarm signal. Near to the radiation receiver there is arranged a reference cell in the direct radiation beam of the radiation source, this reference cell controlling the emission of radiation by the radiation source. Further, there is provided circuitry which, in the presence of a slow change in the amplitude of the receiver output pulse, adjusts an amplitude threshold value set for the amplitude of the receiver output pulse at a rate corresponding to a time-constant of more than one minute. Consequently, there is obtained an output signal of the radiation receiver which is dependent upon the smoke density and which is independent of the contamination or soiling of the smoke detector.

Scattered radiation smoke detector
United States Patent 4,642,471
Inventor(s): Guttinger, Hannes; Pfister, Gustav
Assignee Cerberus AG
Issued: 1987 02 10 Filed: 1984 04 16

Abstract

In a scattered radiation smoke detector (D) the energy supply from the evaluation unit (A) and the signal returned thereto take place exclusively optically by means of radiation conducting elements (L.sub.1, L.sub.2) and all electrical components are situated in the evaluation unit (A) remote from the smoke detector (D). An approximately parallel transmitting or reception zone of small diameter is generated by collimating devices (4, 6) disposed at the ends (3, 8) of the optical conductors and thereby the interference radiation level in the smoke detector is reduced and the sensitivity increased. Since the smoke detector (D) comprises no metallic components, it is insensitive to temperature and corrosion and is especially well suited for application in environments subject to the danger of explosion and electrical interference.

Combustion products detector with accelerated test
United States Patent 4,539,556
Inventor(s) Dederich, Stanley S.; Schoenfelder, George A.; Koster, William M.
Assignee Pittway Corporation

Issued: 1985 09 03 Filed: 1983 04 15

Abstract

A battery-powered photoelectric smoke detector periodically samples the air in a smoke chamber. A manually-operated test button is provided for simulating smoke to test the device. The sampling frequency is determined by a first resistance. A frequency changing circuit includes a test switch, the movable contact of which is coupled to the test button and is responsive to operation thereof for connecting it parallel with the first resistance the series combination of a diode and a second resistance for increasing the sampling frequency. Means are provided for back-biasing the diode to disable the frequency changing circuit when the detector detects smoke.

Fire detector for discriminating smoke and flame based on optically measured distance

United States Patent 5,225,810Inoue, et. al.Jul. 6, 1993

Inventors: Inoue; Masao (Tokyo, JP); Igarashi; Yoshinori (Tokyo, JP). Assignee: Nohmi Bosai Ltd. (Tokyo, JP). Appl. No.: 748,187Filed: Aug. 20, 1991

Abstract

A fire detection apparatus discriminates white smoke, black smoke and flame in a protected area based on changing characteristics of optically measured distances. The apparatus includes a distance meter having a light emitter for emitting a pulse of light energy towards a reference object, such as a distant wall, and a light detector for receiving the pulse of light energy reflected from the reference object or any intervening object. A distance to the reference object or the intervening object is determined based on the lapse of time from the emission to the detection of the pulse of light energy. White smoke is deemed detected when the distance measured is less than a reference difference and is substantially free of fluctuations. Black smoke is detected when the distance measured is more than the reference distance and is also substantially free of fluctuations. Flame is detected when the distances measured differ from the reference distance and fluctuates substantially.

Contrast smoke detector

United States Patent 4,614,968

Inventor(s) Rattman, William J.; Marchetti, Stephen; Galvin,Aaron A.

Assignee American District Telegraph Company

Issued: 1986 09 30 Filed: 1982 02 16

Abstract

A system for detection of smoke by measuring changes in the contrast of a multi-contrast target disposed remotely from a photoelectric sensor. The obscuration of the detection path causes a reduction in the contrast of the sensed target, and a change of predetermined magnitude is employed to trigger an alarm. The target has one or more relatively darker and one or more relatively lighter areas which are viewed by the sensor. The sensor can be composed of a plurality of photosensors each viewing a respective area of the target. Or, the sensor can be a single scanning sensor such as a video camera. Only a single line or segment of a line of the video frame pattern need be employed to monitor the target. The video camera can be employed on a shared basis for providing smoke monitoring

and detection, together with other functions, such as intrusion detection, access control, or visual surveillance of an area.

Optical smoke detector
United States Patent 4,249,169
Inventor(s) Malinowski, William J.
Issued: 1981 02 03 Filed: 1979 05 18
Abstract
A reflected light optical smoke detector includes a thermistor in series with a light emitting diode connected in parallel to a photo-resistive cell. Alarm circuitry is connected to the photocell having a voltage output which is a function of the presence or absence of smoke in an examination zone illuminated by the light source and visible to the cell. The circuit is temperature-compensated automatically by the thermistor since the thermistor will increase the current to the LED in the event of an increase of ambient temperature. The increase in the LED light output will compensate for the loss of photocell sensitivity in the event of an increase in temperature.

Thermal Sensing

Pneumatic pressure detector for fire and ground fault detection
United States Patent 5,691,702HayNov. 25, 1997
Inventors: Hay; Wayne R. (Pleasant Hill, CA). Assignee: Whittaker Corporation (Concord, CA). Appl. No.: 525,190Filed: Sept. 8, 1995
Abstract
Electrical circuitry associated with a pneumatic pressure detector for use in an overheat condition or fire alarm system for aircraft. The pressure detector comprises a plenum situated between a pair of deformable diaphragms and pressurized by a capillary type sensor containing an absorbed gas. A control electronics stage is located remotely from the pressure detector stage and is connected thereto by a single wire extending between them. The control electronics stage senses integrity failure of the pressure detector, an overheat or fire condition, and a ground fault in the connection between the two stages and provides corresponding output indications. The circuitry also includes ground connections at the control electronics stage and the pressure detector, respectively.

Fiber optic based fire detection and tracking system
United States Patent 5,144,125Carter, et. al.Sept. 1, 1992
Inventors: Carter; Hudson R. (Granville, OH); Koksal; Cevdet G. (Alliance, OH). Assignee: The Babcock & Wilcox Company (New Orleans, LA). Appl. No.: 626,605Filed: Dec. 12, 1990
Abstract
An apparatus and method is disclosed for a fiber optic based fire detection and tracking system. An optical time domain reflectometer (OTDR) interrogates at least one optical fiber with a melting point defining a threshold temperature for fire detection. The OTDR measure the time of flight of a light pulse originating at each optical fiber input end and

reflected back to determine the linear position of interruptions along an optical fiber which allows for fire detection and location.

Apparatus for detecting a fire having a liquid filled sensor tube and compensation for changes in ambient temperature

United States Patent 5,621,389FellowsApr. 15, 1997

Inventors: Fellows; Robert A. (San Ramon, CA). Assignee: Whittaker Corp. (Concord, CA). Appl. No.: 463,973Filed: Jun. 5, 1995

Abstract

A fire detection system includes an elongated liquid filled tube with a fluid coupled alarm switch, with a flexible diaphragm which senses a change from the liquid to vapor phase in the presence of an overheat or fire condition to provide an alarm. To prevent false alarms due to normal expansion of the liquid under changing ambient temperature conditions, a compensator is provided which in one form is a pair of mechanically coupled bellow type containers, filled with the same liquid which will expand at the same rate as the fluid under normal ambient temperature conditions but in a fire condition will resist faster expansion thus causing the alarm switch to be actuated. In another embodiment, a bimetallic bellows is utilized to match the liquid expansion but resist greater vapor pressure. Yet in another embodiment the change in liquid flow rate due to a fire condition is sensed to prevent further accommodation to the normal increase in volume of the liquid. This is done by a flexible diaphragm or a floating seal ball.

Compact and lightweight pneumatic pressure detector for fire detection with integrity switch

United States Patent 5,136,278Watson, et. al.Aug. 4, 1992

Inventors: Watson; Nigel S. (Martinez, CA); Pickton; Shailer T. (Lafayette, CA). Assignee: Systron Donner Corporation (Concord, CA). Appl. No.: 669,918Filed: Mar. 15, 1991

Abstract

A pneumatic pressure detector for use in an overheat or fire alarm system utilizes a known capillary type sensor tube which has absorbed in it a gas. Overheat or fire condition causes the gas to expand which then actuates an associated deformable diaphragm to close an electrical switch. To insure that the system pressure is maintained and no fault condition exists, the compact detector also uses a deformable diaphragm associated with an integrity switch which opens if the pressure falls below normal. Both of these diaphragms are juxtaposed to form the plenum to which the sensor tube is attached thereby saving weight and space.

Thermal analog fire detector

United States Patent 5,436,614Torikoshi, et. al.Jul. 25, 1995

Inventors: Torikoshi; Yasuo (Kawasaki, JP); Ishii; Hiromitsu (Chiba, JP). Assignee: Hochiki Kabushiki Kaisha (Tokyo, JP). Appl. No.: 87,502Filed: Jul. 2, 1993

Abstract

A thermal analog fire detector which is excellent in measurement precision and resolution in both the high and low temperature ranges and which has a wide range of measuring temperatures. A constant voltage E from a constant voltage circuit is supplied to a CPU,

an A/D converter and a constant current circuit. The constant current circuit is connected in series to a thermistor. The constant current circuit is constructed to supply a constant current, the value of which being variable in a plurality of stages, to the thermistor controlled by the CPU. The CPU switches the constant current of the constant current circuit according to the measured temperature data. A voltage V across the thermistor is converted into digital data by the A/D converter, and then the converted data is supplied to the CPU.

Low amperage dual sensing fire detector

United States Patent 5,198,801Duggan, et. al.Mar. 30, 1993

Inventors: Duggan; Jack (Markham, CA); Heslop; Michael J. (Rexdale, CA). Assignee: Fire Detection Devices Ltd. (Markham, CA). Appl. No.: 466,864Filed: Jan. 18, 1990

Abstract

A resettable fire detection device comprises in combination a rate of temperature rise sensor, an electronic fixed temperature sensor, and electronic circuitry connected to both circuits for producing an alarm signal if either sensor is activated and for maintaining the alarm signal once the device has been activated. This resettable fire detection device has many uses: specifically, it can be used as a replacement device for a smoke detector device commonly used on ships. In this case, the device draws a very low amperage for use on a parallel circuit common wih smoke detectors. In addition, a time delay circuit can be associated with each of the sensors to avoid false alarms and to accommodate certain environmental conditions. The resettable nature of both the fixed temperature and rate of rise temperatue sensor allows full testing of each device while allowing a remote reset signal to be used to reset the device. In a preferred form, the rate of temperature rise sensor is a mechanical arrangement.

Chemical Sensor Technology

Dew point measurement and time trend analysis

United States Patent 4,506,994

Inventor(s) Schwab, Carl E.

Assignee General Signal Corporation

Issued: 1985 03 26 Filed: 1982 09 20

Abstract

A method and apparatus for determining the dew point or dew point depression which is arranged for unattended operation and is extremely accurate in the vicinity of very small dew point depressions. In addition to measuring present dew point depression, historical records are maintained and the device is arranged to perform a time trend analysis so as to provide for short term future prediction. Output is provided via a voice synthesizer and a radio. Dew point depression is computed by determining the adiabatic change in volume required to produce condensation. The change in volume is produced by rapidly expanding a test chamber. The measurement cycle concludes with a compression step to raise chamber temperature to at least freezing.

Fire detection system using spatially cooperative multi-sensor input technique
United States Patent 5,079,422WongJan. 7, 1992
Inventors: Wong; Jacob Y. (Santa Barbara, CA). Assignee: Gaztech Corporation (Goleta, CA). Appl. No.: 583,234Filed: Sept. 13, 1990

Abstract
A system for detecting fires uses at least two carbon dioxide sensors positioned at spaced locations in a room. Each sensor produces an electrical output signal representative of the carbon dioxide concentration in its vicinity. A computer calculates the ratio of the concentration sensed by each sensor to the concentration sensed by each of the other sensors, and any imbalance in the distribution of carbon dioxide will be reflected in these ratios. Random variations prevent the ratios from being equal, and the magnitude of the random variations is quantized by calculating the standard deviation of the ratios. The ratios are then normalized and compared to a threshold level that corresponds to a chosen false alarm rate.

Odor concentration measurement method and apparatus for use in fire detection
United States Patent 5,623,212YamanakaApr. 22, 1997
Inventors: Yamanaka; Shigeo (Tokyo, JP). Assignee: Nohmi Bosai Ltd. (Tokyo, JP). Appl. No.: 404,096Filed: Mar. 14, 1995

Abstract
An odor concentration is measured by energizing an odor sensor connected across a power supply through a load resistance. A total resistance of the odor sensor is represented by and includes a parallel connection of a first resistive component having a value according to surrounding environmental conditions and a second resistive component having a value according to an odor concentration, and a saturation resistive component connected in series with the parallel connection of the first and second resistive components. A CPU is used to measure the odor concentration by obtaining the value of the second resistive component from an output of the odor sensor which is a voltage across the load resistance. Also, the measured odor concentration can be normalized and compared with a given threshold for fire detection.

Fire detector
United States Patent 5,767,776WongJun. 16, 1998
Inventors: Wong; Jacob Y. (Santa Barbara, CA). Assignee: Engelhard Sensor Technologies, Inc. (Iselin, NJ). Appl. No.: 593,253Filed: Jan. 29, 1996

Abstract
A fire detector with a maximum average response time of less than 1.5 minutes is obtained by combining a smoke detector with a CO(2) detector that uses NDIR sensor technology. The smoke detector is used to detect smoldering fires and to help prevent false alarms attributable to the CO(2) detector. The CO(2) detector is used to rapidly detect fires by measuring the rate of change of CO(2) concentration. A signal processor generates an alarm signal when a smoldering fire is detected or alarm logic indicates that a fire has been detected.

Radiation Sensing

Scan type fire detecting apparatus

United States Patent 5,726,451Ishida, *et. al.* Mar. 10, 1998
Inventors: Ishida; Hiroshi (Tokyo, JP); Asoma; Akira (Tokyo, JP); Izaki; Yuzo (Tokyo, JP). Assignee: Hochiki Corporation (Tokyo, JP). Appl. No.: 510,569Filed: Aug. 2, 1995

Abstract

A scan type fire detecting apparatus is provided with a scanning unit which stepwise scans a monitoring area in a horizontal direction and vertically scans at each step of the horizontal scan to output a detecting signal obtained during the vertical and horizontal scan while a fire judging section judges an occurrence of a fire based on the detecting signal from the scanning unit. The fire judging section includes a first fire judging section which judges as to whether or not the detecting signal outputted from the scanning unit during the vertical and horizontal scanning is higher than a predetermined threshold value, and stops the horizontal scan of the scanning unit when the detecting signal is higher than the predetermined threshold value. A second fire judging section vertically scans the scanning area at the horizontal stop position, determined by the first fire judging section, and analyzes a frequency of the detecting signal detected through the vertical scan to judge whether or not the detecting signal is on the basis of a fluctuation of a flame, to thereby determine an occurrence of a fire when it is judged that the detecting signal is on the frequency of the fluctuation of a flame.

Fire detection system

United States Patent 5,153,722Goedeke, et. al.Oct. 6, 1992
Inventors: Goedeke; A. Donald (Newport Beach, CA); Drda; Benedict (Costa Mesa, CA); Viglione; Sam (Santa Ana, CA); Gross; H. Gerald (Santa Ana, CA). Assignee: Donmar Ltd. (Newport Beach, CA). Appl. No.: 641,166Filed: Jan. 14, 1991

Abstract

A fire detection system includes a color video camera, a frame grabber and a computer processor operative to store and examine a series of image frames of the viewed area. Ultraviolet and infrared detectors produce event signals when energy received exceeds predetermined thresholds. The processor then rapidly evaluates the images from the camera to determine bright area objects, their location, edge profile, edge flicker, stationarity and spectral characteristics as well as spectral flicker to confirm a fire event. Finally, the size of a confirmed fire image is measured as a final criterion for the release of fire suppressant material, either in a limited zone within which the fire is located or within the entire facility.

Dual channel multi-spectrum infrared optical fire and explosion detection system

United States Patent 5,612,676Plimpton, *et. al.* Mar. 18, 1997 Inventors: Plimpton; Jonathan C. (Canterbury, NH); Minott; George L. (Wilton, NH). Assignee: Meggitt Avionics, Inc. (Manchester, NH). Appl. No.: 153,801Filed: Nov. 16, 1993

Abstract

A fire detection system including two optical sensing channels and signal processing circuitry that processes the two sensing channels' output signals and generates another output signal when the processed signals are indicative of a fire. The system

automatically detects hydrocarbon and certain non-hydrocarbon fueled fires. The first sensing channel simultaneously senses IR radiation in two IR spectral regions having separate and distinct bandwidths and generates a first signal corresponding to incident IR radiation being sensed in at least one of these spectral regions. One bandwidth is selected so the first sensing channel is responsive to the IR radiation emitted by hydrocarbon and/or certain non-hydrocarbon fueled fires and the other bandwidth is selected so the first sensing channel is responsive to IR radiation emitted from hydrocarbon fueled fires. Both bandwidths are selected so the first sensing channel is essentially non-responsive to solar IR radiation. The second sensing channel simultaneously senses IR radiation in three IR spectral regions, defined by separate and distinct bandwidths, and generates a second signal corresponding to the incident IR radiation being sensed in at least one of the these spectral regions. Each second channel spectral region bandwidth is selected so the second sensing channel is responsive to IR radiation emitted by non-fire radiation sources but non-responsive to IR radiation in the first channel spectral regions.

Method for detecting a fire condition

United States Patent 5,373,159Goldenberg, *et. al.* Dec. 13, 1994

Inventors: Goldenberg; Ephraim (Tel Aviv, IL); Olami; Tal (Beersheba, IL); Arian; Jacob (Beersheba, IL). Assignee: Spectronix Ltd. (Tel Aviv, IL). Appl. No.: 115,066Filed: Sept. 2, 1993

Abstract

A method of detecting a fire condition in a monitored region includes concurrently monitoring the region by a first sensor sensitive to radiation within a first bandwidth which includes the CO(2) emission band, by a second sensor sensitive to radiation within a second bandwidth which includes wavelengths mainly lower than the CO(2) emission band, and by a third sensor sensitive to the radiation within a third bandwidth which includes wavelengths higher than the CO(2) emission band. The measurements of all these sensors are utilized in determining the presence or absence of the fire condition in the monitored region.

UV/IR fire detector with dual wavelength sensing IR channel

United States Patent 5,311,167Plimpton, et. al.May 10, 1994

Inventors: Plimpton; Jonathan C. (Northfield, NH); Minott; George L. (Wilton, NH). Assignee: Armtec Industries Inc. (Manchester, NH). Appl. No.: 745,017Filed: Aug. 14, 1991

Abstract

A system for automatically detecting fires fueled by hydrocarbons and certain non-organics including hydrogen, hydrazine, magnesium, aluminum, potassium, ammonia and silane, which system has a low incidence of false alarms from incident radiation emitted by non-fire radiation sources such as the sun. The system includes a UV sensor assembly that both senses UV radiation in a predetermined spectral bandwidth and generates a first signal corresponding to the sensed radiation; an IR sensing assembly consisting of a single IR sensor that simultaneously senses IR radiation in two predetermined spectral bandwidths and generates a second signal corresponding to the IR radiation in at least one of the spectral regions; and a signal processor. The UV spectral bandwidth is such that the UV sensing assembly is responsive to UV radiation emitted by hydrocarbons and certain non-organics but non-responsive to solar UV radiation. The IR spectral bandwidths are selected so that one spectral region is responsive to IR radiation emitted by hydrocarbons and certain non-organics while the other is responsive to hydrocarbons only. Both IR spectral regions are selected so as to be largely non-responsive to solar IR radiation. The signal processor processes the first and second signals and generates a fire signal when the processed signals are indicative of a fire.

Detecting the presence of a fire

United States Patent 5,612,537Maynard, et. al.Mar. 18, 1997

Inventors: Maynard; Steven P. (London, GB3); Basham; Paul J. (High Wycombe, GB3); Pleydell; Mark E. (West Drayton, GB3). Assignee: Thorn Security Limited (Middlesex, GB2). Appl. No.: 298,307Filed: Sept. 1, 1994

Abstract

Apparatus for detecting the presence of a fire includes a pair of detectors for radiation characteristic of a fire, e.g. at 4.3 microns, and a further detector for radiation characteristic of a black body, e.g. at 3.8 microns. Filters select the detector output components at flame flicker frequencies. The filtered outputs of the detector pair are cross-correlated to produce a relatively noise-free signal. This signal is divided by a factor obtained by cross-correlating the further detector filtered output with the average of the detector pair filtered outputs. The result of the division is applied to a threshold-responsive circuit. Thus the relatively noise-free signal is effectively subjected to a threshold which is proportional to the degree of similarity between the variations with time of the output signal of the further detector and the output signals of the detector pair.

Multi-Sensor Technology

Practical and improved fire detector

United States Patent 5,691,704WongNov. 25, 1997

Inventors: Wong; Jacob Y. (Santa Barbara, CA). Assignee: Engelhard Sensor Technologies, Inc. (Iselin, NJ). Appl. No.: 593,750Filed: Jan. 29, 1996

Abstract

A fire detector which combines an NDIR CO(2) gas detector with a photoelectric smoke detector to minimize false alarms by logic means that can be integrated into a single chip that can have an ASIC section and a microprocessor section. The NDIR CO(2) detector can be single or dual channel. The NDIR CO(2) gas detector and the photoelectric smoke detector can be separate or combined in a single device in which they are optically isolated by a light-tight barrier but still use a common light source. Also, the CO(2) and smoke detectors can be combined on a single substrate within a common housing.

Multi-signature fire detector

United States Patent 5,691,703Roby, et. al.Nov. 25, 1997

Inventors: Roby; Richard J. (Columbia, MD); Gottuk; Daniel T. (Columbia, MD); Beyler; Craig L. (Columbia, MD). Assignee: Hughes Associates, Inc. (Columbia, MD). Appl. No.: 487,050Filed: Jun. 7, 1995

Abstract

A multi-signature fire detection method and apparatus, utilizing first and second detectors for detecting first and second fire signatures. The first detector outputs a first signal indicative of the first detected fire signature, and the second detector outputs a second signal indicative of the second detected fire signature. A signal processor is provided for combining the first and second signals using a number of correlations, wherein outputs of the first and second detector means are coupled to the signal processor, and the signal processor compares and combines the first and second signals to a first predetermined reference value, and outputs a fire condition signal if a combination of the first and second signals exceeds the predetermined reference value.

Fire detector

United States Patent 5,351,034Berger, et. al.Sept. 27, 1994

Inventors: Berger; Horst (Kaarst, DE); Krippendorf; Tido (Dusseldorf, DE); Politze; Heiner (Neuss, DE). Assignee: Esser Sicherheitstechnik GmbH (Neuss, DE). Appl. No.: 845,916Filed: Mar. 4, 1992

Abstract

A fire detector includes a scattered light detector unit and an ionization detector unit which are arranged upon a common base at each side of the center axis of a compartment defined by the base and a peripheral wall extending from the base. The scattered light detector includes a light source and a receiver, with their principal axes intersecting in a point of intersection which is positioned at one side of the center axis of the compartment and thus extends eccentric to the center axis. The ionization detector unit includes a holder for a preparation to be ionized, with the holder being arranged at the other side of the center axis. Suitably, a heat detector is further provided in the center axis.

Combination smoke, carbon monoxide, and hydrocarbon detector

United States Patent 5,801,633SoniSept. 1, 1998

Inventors: Soni; Govind (4559 N. Bernard #2, Chicago, IL 60625). Appl. No.: 842,223Filed: Apr. 24, 1997

Abstract

A combination smoke, carbon monoxide and hydrocarbon detector including a smoke detection mechanism adapted to transmit a smoke signal upon the detection of smoke, a carbon monoxide detection mechanism adapted to transmit a carbon monoxide signal upon the detection of carbon monoxide, and a hydrocarbon detection mechanism adapted to transmit a hydrocarbon signal upon the detection of hydrocarbon. Next provided is an audio alarm mechanism situated within the housing and connected to the each detection mechanism. The audio alarm mechanism is adapted to emit a high intensity audio alarm upon the receipt of a signal, whereby the type of audio alarm is unique to the signal received. Further provided is control circuitry having a first mode of operation when only one signal is received from the detection mechanism whereby the control circuitry continuously transmits the one signal to the audio alarm means upon the receipt thereof. The control circuitry further having a second mode of operation when more than one signal is received from the detection mechanism whereby the control circuitry alternately transmits each of the signals to the audio alarm mechanism.

Composite fire sensor
United States Patent 4,640,628
Inventor(s) Seki, Hiroshi; Kataishi, Ryuichiro
Issued: 1987 02 03 Filed: 1985 07 11

Abstract

A composite fire sensor comprising a first sensor element sensitive to a change in incident infrared rays, a second sensor element having a variable electric conductivity according to gas absorption/desorption, at least one comparator for combining the outputs of the first and second sensor elements, and a delay circuit for delaying the output of at least one of the comparators. Predetermined reference voltages are supplied to the comparators.

Alarm system having plural diverse detection means
United States Patent 4,319,229
Inventor(s) Kirkor, Gabriel
Assignee Firecom, Inc.
Issued: 1982 03 09 Filed: 1980 06 09

Abstract

A system for detecting a fire emergency condition employs three separate and diverse sensors; a heat detector, a smoke detector, and an infrared radiation detector. Either or all of these detectors can activate the alarm. Additionally, the infrared radiation detector can be used to control the energization of the room's artificial illumination means. All sensors are mounted in a common housing and a mirror or lens arrangement is provided to focus the infrared radiation upon the appropriate detector.

False alarm resistant fire detector with improved performance
United States Patent 5,798,700
Inventors: Wong; Jacob Y. (Santa Barbara, CA). Assignee: Engelhard Sensor Technologies, Inc. (Iselin, NJ). Appl. No.: 744,040Filed: Nov. 5, 1996

Abstract

A fire detector having a greatly reduced frequency of generating false alarms. An AND gate is responsive to outputs from first and second fire detector modules that are responsive to the detection of first and second characteristics of a fire, respectively, to signal the detection of a fire if both of these characteristics have been detected. At least one override path is included to enable the occurrence of a particular type of fire to be signaled that would not otherwise be signaled by the output of said AND gate.

Signal Processing

Fire alarm system
United States Patent 4,803,469
Inventor(s) Matsushita, Eiji
State/Country JPX
Assignee Hochiki Corporation
Issued: 1989 02 07 Filed: 1986 07 14

Abstract
A fire alarm system which comprises one or more detecting sections for detecting a change in the surrounding phenomena due to a fire in an analog form; a storing section for storing the analog data output from the detecting section or sections; a level comparing section for comparing a data level represented by present instantaneous analog data output from the detecting section or sections and a predetermined level; fire judging instructing section which extracts a plurality of data stored during a predetermined period of time back to from the time when a comparison signal is obtained from the level comparing section, calculates a change amount between the respective extracted data and generates an output for initiating the calculation when the number of the calculated change amounts exceeding a predetermined amount exceeds a predetermined number; and a fire judging section for receiving the data stored in the storing section in response to the signal from the comparing section and/or fire judging instructing section to judge a fire.

Fire alarm system
United States Patent 4,796,205
Inventor(s) Ishii, Hiromitsu; Yamauchi, Yukio
State/Country JPX
Assignee Hochiki Corp.
Issued: 1989 01 03 Filed: 1985 08 12

Abstract
A fire alarm system which makes fire determination based on a novel idea which considers various changes of the physical phenomena in the surroundings caused in relation with the occurrence of a fire in terms of changes of vectors. These changes in the physical phenomena are detected by the detecting section in the form of analog data and processed by a data sampling section as sampled data and stored in a storing section in such a manner as discriminating them by the detecting sections. The tendencies of the changes are computed in a first computing section and the vectors representing the present or future conditions of the physical phenomena are computed from the sampled data. The vector is compared in a comparing section with a preliminarily set data related to the fire detection and when the relation therebetween is not a predetermined one, an alarm is given through an alarming section.

Early stage fire detecting apparatus
United States Patent 5,673,020OkayamaSept. 30, 1997
Inventors: Okayama; Yoshiaki (Tokyo, JP). Assignee: Nohmi Bosai Ltd. (Tokyo, JP).
Appl. No.: 412,272Filed: Mar. 28, 1995

Abstract
An early stage fire detecting apparatus is arranged such that a fire state is discriminated based on a fire probability output from a signal processing network. The fire probability being prepared in such a manner that outputs from a high sensitivity smoke sensor SS and a smell sensor NS, from which responses can be obtained at the early stage of a fire, are subjected to signal processing. Fire information composed of a value at a given moment of smoke and a difference indicating the increase or decrease of the value at a given moment of the smoke and a value at a given moment of smell and a difference indicating

the increase or decrease of the value at a given moment of the smell are input to the signal processing network. The signal processing network outputs the above fire probability based on a table (RAM12) defining a fire probability to be obtained from the above fire information and weighting values (RAM13). With this arrangement, an early stage fire can be detected by explicitly excluding non-fire factors such as tobacco, steam vapor, the smell of coffee, and the like.

Count discriminating fire detector
United States Patent 4,260,984
Inventor(s) Honma, Hiroshi
Assignee Hochiki Corporation
Issued: 1981 04 07 Filed: 1980 03 13

Abstract

A detecting circuit is responsive to the change in a physical parameter indicative of a fire such as smoke, heat, flame or the like, and a comparator circuit connected to the detecting circuit produces detection pulses in synchronism with an oscillator circuit when the change in the physical parameter exceeds a predetermined amount. A counter circuit counts the detection pulses and produces an output which triggers a switching circuit when a predetermined number of consecutive detection pulses are counted. When triggered, the switching circuit transmits an alarm signal to an alarm receiving panel. Connected between the counter circuit and the switching circuit is a monostable multivibrator having a time constant which is equal to or smaller than the supply voltage rise time constant of the counter circuit so as to prevent the trigger signal from being applied to the switching circuit during the transition period immediately following the connection of the power source. A detection sensitivity validation means directs the detection pulses from the comparator circuit to the outside so as to facilitate the sensitivity adjustment.

Fire alarm system
United States Patent 4,884,222
Inventor(s) Nagashima, Tetsuya; Matsushita, Eiji; Yuchi, Sadataka; Kitajima, Akira
State/Country JPX
Issued: 1989 11 28 Filed: 1985 07 29

Abstract

A fire alarm system of the present invention is adapted to compute an approximation equation based on the detection data from a detector or detectors such about a smoke density, a temperature, a gas concentration, etc. and predictively determine a fire based on the approximation equation. The system including computing section for computing an approximation equation approximating a change in the physical phenomenon related to the occurrence of a fire which is output from the detector or detectors, sequentially sampled and stored and for computing a future value of the phenomenon estimated from the approximation by using a predetermined number of the data stored in a storing section. The future vale is compared with a data value preliminarily set in association with the fire alarming and an alarm is generated when the relation there between is not within a predetermined range.

Fire detecting apparatus

United States Patent 5,671,159MoritaSept. 23, 1997

Inventors: Morita; Toshikazu (Tokyo, JP). Assignee: Nohmi Bosai Ltd. (Tokyo, JP). Appl. No.: 346,229Filed: Nov. 22, 1994

Abstract

A fire detecting apparatus is designed to have improved reliability by reducing the possibility that the apparatus is influenced by an environmental change, external noise or the like which would otherwise cause erroneous fire information to be sent to a receiving unit to generate a false alarm. The apparatus includes a light emitting device for detecting a physical quantity of a fire phenomena such as smoke, a light receiving device, an A/D conversion circuit, a RAM for successively storing a predetermined number of latest detection outputs from the A/D conversion circuit, an MPU for calculating deviations between the predetermined number of latest detection outputs stored in the RAM and for calculating an average value of at least two of the detection outputs having the smallest deviation, and a transmitting/receiving circuit for sending the average value calculated by the MPU as a physical quantity of the fire phenomenon.

Fire detector

United States Patent 5,670,948Mochizuki, et. al.Sept. 23, 1997

Inventors: Mochizuki; Mikio (Tokyo, JP); Hirooka; Eiji (Tokyo, JP); Yasukawa; Makoto (Tokyo, JP). Assignee: Nohmi Bosai Ltd. (Tokyo, JP). Appl. No.: 63,422Filed: May 19, 1993

Abstract

A fire detector capable of readily and accurately adjusting the sensitivity thereof and of not erroneously outputting any fire signal is provided with a first-stage amplifying circuit having an output adjusting variable resistor and a fire discriminating section having a reference voltage adjusting variable resistor. As a result, it is possible to adjust the amplified output to a predetermined value by the switching level of the fire discriminating section to a predetermined value by the reference voltage adjusting variable resistor.

Fire detector and fire receiver

United States Patent 5,627,514MoritaMay 6, 1997

Inventors: Morita; Toshikazu (Tokyo, JP). Assignee: Nohmi Bosai Ltd. (Tokyo, JP). Appl. No.: 399,598Filed: Mar. 7, 1995

Abstract

A fire detector is capable of self-detecting its own malfunction and is also capable of quickly announcing a failure of high-level emergency in the fire detector. A plurality of determining values are established for the output level of a physical quantity detector for detecting the physical quantity of a fire phenomenon such as smoke, and a different time is set for each of the determining values. A shorter time is set for greater deviation from the normal value of the output level. It is determined that the physical quantity detector is faulty if it is detected that the output level of the physical quantity detector continuously exceeds any of the established determining values for not less than the time which has been set for that particular determining value.

Adaptive fire detector

United States Patent 5,369,397WongNov. 29, 1994

Inventors: Wong; Jacob Y. (Santa Barbara, CA). Assignee: Gaztech International Corporation (Goleta, CA). Appl. No.: 874,394Filed: Apr. 27, 1992

Abstract

The fire detector includes a carbon dioxide sensor and a microcomputer. When the rate of increase of the concentration of carbon dioxide at the sensor exceeds a threshold, an alarm is produced. The threshold is set at one of three possible levels by the microcomputer in response to the state of the atmosphere at the sensor as determined by the microcomputer based on several variables that are derived from the sensed concentration of carbon dioxide. The derived variables include the average concentration of carbon dioxide, the average rate of change of carbon dioxide concentration, the monotonicity of the increase or decrease of the carbon dioxide concentration and the range of concentrations sensed in each cycle of operation. The threshold setting is determined every ten seconds. In this way, the setting of the rate threshold is responsive to variations in the carbon dioxide level at the sensor that are caused by entities other than a fire, such as the presence or absence of people in a closed room.

Fire alarm system and method employing multi-layer net processing structure of detection value weight coefficients

United States Patent 5,281,951OkayamaJan. 25, 1994

Inventors: Okayama; Yoshiaki (Tokyo, JP). Assignee: Nohmi Bosai Kabushiki Kaisha (Tokyo, JP). Appl. No.: 490,582Filed: May 14, 1990

Abstract

A fire monitoring system detects a plurality of types of detection information using a plurality of fire phenomenon detectors for detecting physical quantities caused by fire phenomena or using a plurality of detectors each including at least one fire phenomenon detector and at least one environment detector provided in association with the fire phenomenon detector. The plurality of types of detection information undergo consolidated signal processing for obtaining one or more types of fire information for realizing fire monitoring. The fire monitoring system includes a table for storing a specific set of values one for each type of detection information and a corresponding set of values for each type of fire information to be obtained when the specific set of values of detection information is supplied, and a signal processing net having a multilayer structure responsive to the input of respective values for the types of detection information to thereby impart corresponding weights to each value of the input detection information in accordance with the degree of contribution thereof to each value of fire information and to arithmetically determine each value of fire information on the basis of the weighted detection information values. In a learning mode, the weights are adjusted that a value for each type of fire information determined arithmetically when the specific set of values of detection information placed in the table is supplied to the signal processing net approximates the value for each type of fire information contained in the table.

Self-adjusting smoke detector with self-diagnostic capabilities

United States Patent 5,798,701Bernal, et. al.Aug. 25, 1998

Inventors: Bernal; Brian A. (Charlotte, NC); Croft; Daniel P. (Beaverton, OR); Johnson; Kirk R. (Rindge, NH); Marman; Douglas H. (Ridgefield, WA); Peltier; Mark A. (Sherwood, OR). Assignee: SLC Technologies, Inc. (Tualatin, OR). Appl. No.: 807,627Filed: Feb. 27, 1997

Abstract

A smoke detector (10) has internal self-adjustment and self-diagnostic capabilities. It includes a microprocessor-based alarm control circuit (24) that periodically checks the sensitivity of a smoke sensing element (20) to a smoke level in a spatial region (12). The alarm control circuit and the smoke sensor are mounted in a discrete housing (25) that operatively couples the smoke sensor to the region. The microprocessor (30) implements a routine (50) stored in memory (32) by periodically determining a floating adjustment (FLT(--) ADJ) that is used to adjust the output (RAW(--) DATA) of the smoke sensing element and of any sensor electronics (40) to produce an adjusted output (ADJ(--) DATA) for comparison with an alarm threshold. The floating adjustment is not greater than a maximum value (ADJISENS) or less than a minimum value.

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As part of the National Aeronautics and Space Administration (NASA) initiated program on global civil aviation, NIST is assisting the Federal Aviation Administration in its research to improve fire detection in aircraft cargo compartments. Improved fire detection includes both fast (early) fire sensing and immunity to nuisance alarms caused by environmental conditions and hardware faults. Aircraft cargo compartment detection certification methods have been reviewed. Current methods are not capable of evaluating the performance of multi-element detectors, nor detectors based on sensing fire signatures besides smoke; they must be upgraded for that capability. Component testing of detectors that sense chemicals, heat, smoke, or combinations and that might employ complex signal processing algorithms is a challenge. The Fire Emulator/Detector Evaluator (FE/DE) has been designed to evaluate fire detection technologies such as new sensors, multi-element detectors, and detectors that employ complex algorithms. The FE/DE is a flow tunnel that can reproduce velocity, temperature, smoke, and combustion gas levels to which a detector might be exposed during a fire. It is being upgraded to include low temperature operation and moisture variations found in aircraft cargo compartments. In addition, environmental sources such as dust and humidity can be produced to assess the level of immunity to nuisance alarms. A scientific literature survey and patent search have been conducted relating to existing and emerging fire detection technologies, and the potential use of new fire detection strategies in cargo compartment areas has been assessed. In the near term, improved detector signal processing and multi-sensor detectors based on combinations of smoke measurements, combustion gases and temperature are envisioned as significantly impacting detector system performance. Because of the required conversion of most Class D cargo compartments to Class C, a three-fold reduction in nuisance alarm rates will be required to maintain the status quo. If, in the future, detectors employ advanced signal processing with more robust sensing, the resulting nuisance alarm rate reduction would accomplish this and more.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

smoke detectors; fire detection; aircraft compartments; cargo spaces; aircraft fires

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