Vision-Based Cargo Fire Detection System for Commercial Aircraft

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Overview

- Motivation and vision system concept
- Hardware architecture
- Performance requirements specifications
- Image analysis and decision making
- Performance evaluation
- Conclusions

Motivation
Better Detection + Fewer False Alarms

- Better detection of “smokeless” fires

- High false alarm rate of cargo bay fire detection systems
  - good smoke detecting sensitivity
  - approximately 200 false alarms per 1 true alarm (FAA data)
  - A fire alarm requires immediate suppression and diversion to emergency airport
  - Unnecessary diversion may be dangerous
  - long range flights over polar regions
  - emergency airport may lack amenities, pose unnecessary risk

- Addresses false alarm sources
  - Separate detection of Fog and Dust

Vision System Concept

- Separate fire and smoke detection through image processing
  - low-cost CCD cameras in visual and NIR spectrum
  - image integrates data from large area – instead of point sensing
- Visual monitoring of cargo bay
  - video from each camera fed to cockpit
  - crew may select the view
- Digital video recorder function
  - in case of alarm, crew may analyze pre-fire condition
- Fuse other sensor and aircraft data to reinforce decision criteria
  - air pressure, humidity, temperature
  - designed to accept electronic noses and other advanced sensor data
- Expansion potential designed in
  - Automatic intrusion, motion (cargo shifting) detection, easily added
  - Easy integrating other special sensors or interfaces

Video Detection Algorithms

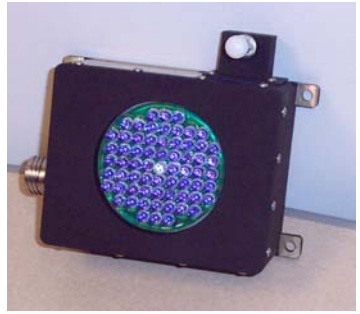
Four Video Detection Functions

- Hot Spot Detection
  - Fast Detection of Hot Spots (>350C) via direct or reflected view
- Smoke Detection
  - Integrated across the full volume of the viewing area, not limited to spot sensing
  - Unique detection algorithms insensitive to velocity or direction of air movement
- Fog Detection
  - Unique detection algorithms that detect both localized fog and fog induced by reduced cargo bay pressure.
- Dust Detection
  - Detects dust up to levels that cause false alarms in current technology sensors

Hardware Architecture

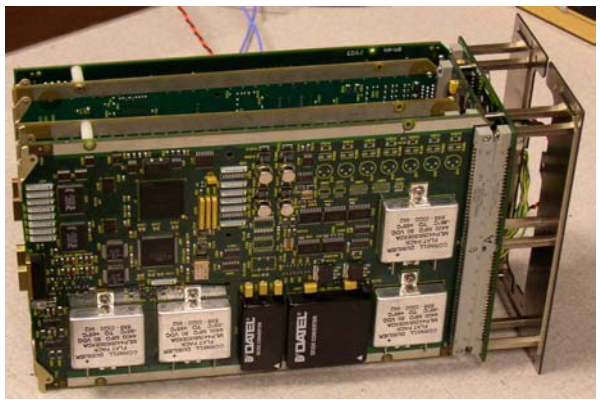
Camera units

- grayscale CCD chip
- switchable LED array
- NIR filter
- DSP for image processing
- NTSC video output
- humidity measurement
- temperature measurement
- CAN bus for data and control



Illumination modules

- switchable LED array
- humidity measurement
- temperature measurement
- CAN bus for data and control
- overhead installation

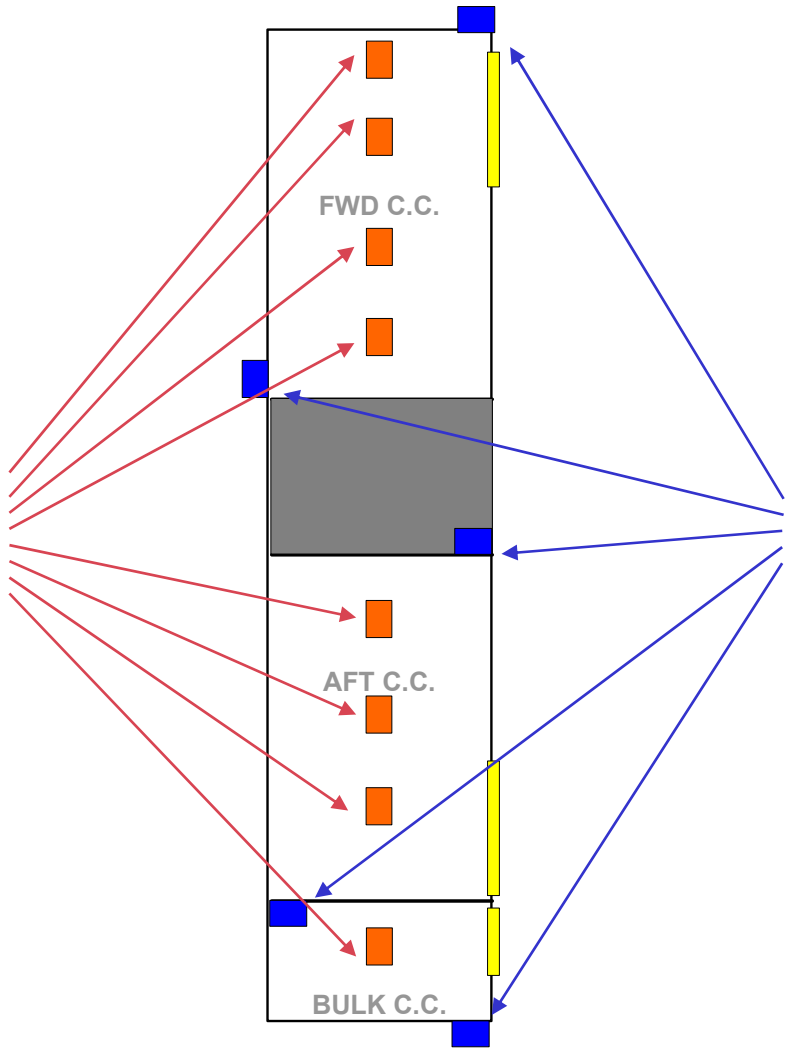


Control unit

- dual lane architecture
- video inputs from up to 8 cameras
- video formatting and enhancement for cockpit display
- hosts fire / hotspot / non – fire decision algorithms
- control of camera and illumination modules
- 10 minute replay buffer for all 8 cameras

Hardware placement

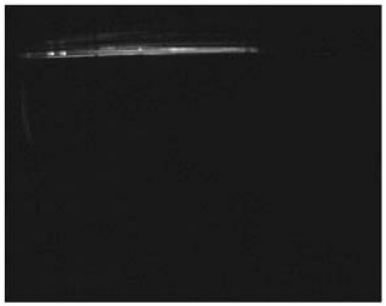
Illumination units
- switched on and off
- placed on ceiling



Cameras
- placed on side walls
- close to ceiling
- view of gap above containers

Use of Light Switching

Non-illuminated view
- all light sources switched off
- bright areas indicate hotspots



Near illumination
- only camera's own light is on
- detection through scattering in smoke

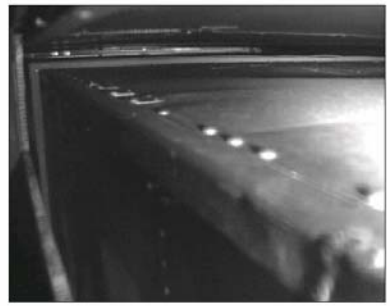
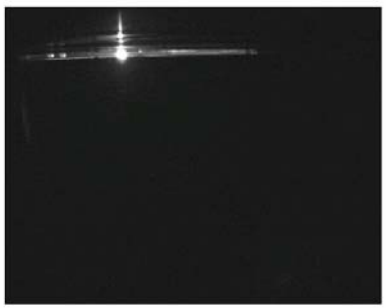
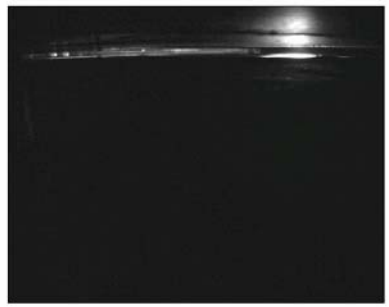


Image Analysis

- Rotating source of lighting provides valuable data for smoke, fog, dust analysis
- Lights continually switched on and off
- Camera settings adjusted according to lighting
- Some views collected more often
  - near illumination needed for cockpit display
- Analysis of different views combined through data fusion





Far illumination
- only opposing camera's light is on
- detection through dimming in smoke

Overhead illumination
- only overhead illumination is on
- detection through scattering in smoke

Performance Requirements Definition

- Video Based Fire Detection Criteria not defined

- Goodrich formed an advisory board
  - University of Duisburg-Essen EN-54 fire experts
  - Experts in shipping widely diverse cargo
  - Built a consensus definition of fire and false alarm performance
  - Developed test guidelines for a vision-based cargo fire detection system

- Final requirements definitions
  - Fire performance specifications based on EN-54 standard test fires
  - False alarm specifications include fog and dust environment
  - Two geometric configurations
    - open view – empty cargo bay
    - hidden view – cargo bay filled with containers
  - Details in the companion paper:
    - W. Krüll, I. Willms, J. Shirer, *Test methods for a video-based Cargo Fire Verification System*,

Image Processing and Analysis

Functions of Distributed processing - performed by each camera's DSP
- Numerical analysis results sent to control unit

- Image enhancement
  - Fish-eye effect correction
  - Intensity/contrast adjustments
  - Built in test address electronics performance, CCD health, dirty lens, etc

- Image feature extraction
  - Intensity statistics
  - Gradient image statistics
  - Spatial distribution moments

- Isolation of trouble spots
  - Edge detection
  - Image segmentation

Fire/Non-fire Discrimination

Functions performed by control unit

- Data fusion based on
  - Image analysis results from individual cameras
  - Non-video measurements from cameras and overhead units
    - temperature, humidity
  - Other data from aircraft data bus
    - flight stage, cabin air pressure
  - Detection data from individual sensors

- Decision making tools
  - Bayesian statistical reasoning
  - Fuzzy logic-derived rules
  - Other suitable decision techniques

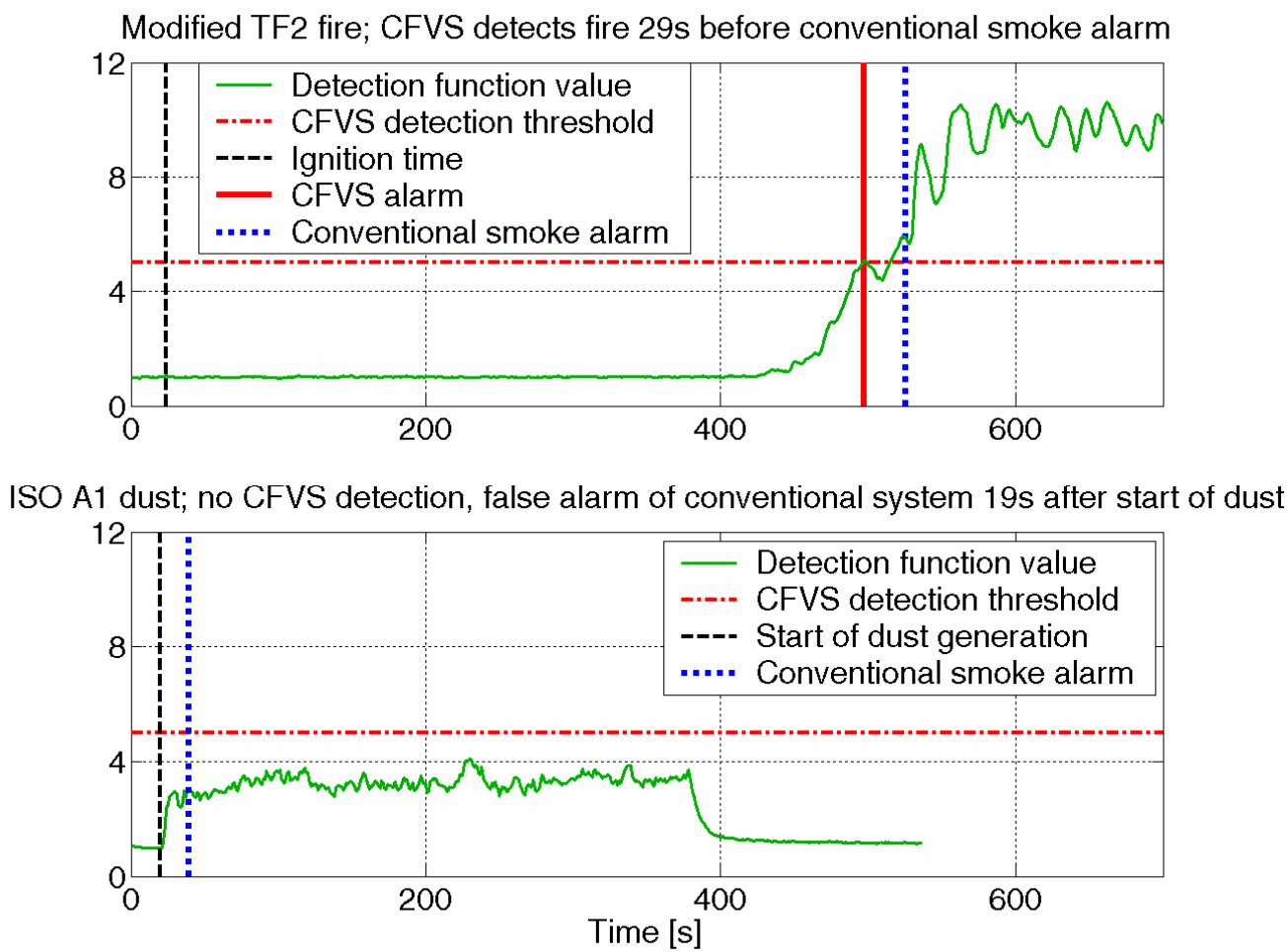
Performance Evaluation

- **Fire performance** (EN-54 modification)
  - 7 test fires in both direct view and hidden view configurations
  - Flaming fires – NIR hot spot detection
  - Smoldering fires – smoke detection through illuminated views
  - **All fires detected faster than by standard smoke detectors**

- **Fog performance**
  - Tests in an altitude chamber
  - Rapid decrease of pressure leading to fog condensation
  - **No false alarm – primary smoke alarm unconfirmed**

- **Dust performance**
  - Tests with ISO A1 and A2
  - Dust density sufficient to produce false alarms on standard A340 detectors
  - **No false alarm – primary smoke alarm unconfirmed**

Performance Example



Hot Spot Detection
Modified TF5 Fire

- The gap between container and ceiling is 4.2 cm
- Fire source is approx. 5.5 m away from camera
- Flame reflections visible in non-illuminated view
- Hotspot area highlighted in composite image

Smoke Detection
Modified TF3 Fire

- The gap between container and ceiling is 4.2 cm
- Smoke source is approx. 5.5 m away from camera
- Smoke scatters overhead light approx. 3.5 m away from camera
- Smoke area highlighted in composite view

Conclusions and comments

- **Superior smoke detection capabilities**
  - access to whole cargo bay area (vs. folded optical path within a sensor)
- **Hot-spot detection in NIR**
  - earlier detection of most EN54-type fires than standard smoke detectors
- **Ability to identify and eliminate false alarms**
  - differentiates fog and dust from smoke
- **Image and video recording**
  - human analysis of pre- and post-fire detection condition
- **Video surveillance function**
  - motion and intrusion detection easily added

The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference