Electronic Design

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How Thermal Visible Imaging is Primed for Early Fire Detection

Traditional fire-detection strategies that only react after smoke and flames appear are insufficient for protecting high-value, high-uptime assets such as industrial and compute infrastructure.

Fire is a systemic threat to global digital continuity and energy security. Intensive electrification of infrastructure and the rapid expansion of high-density computing and energy storage are fundamentally altering the thermal dynamics of facilities across many industries.

A steady drumbeat of news reports about fire-related industrial accidents has raised new concerns over the timeless challenges of aging infrastructure, complex regulatory requirements, hazardous materials, and the risks posed by climate and political volatility.

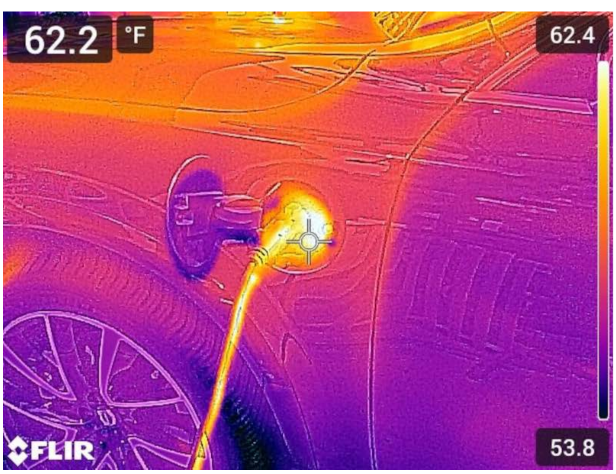
Traditional fire-detection strategies, long reliant on reactive sensors that trigger only after smoke or open flames appear, are now insufficient for the protection of high-value, high-uptime assets. This drives the current transition toward early fire detection (EFD). Thermal imaging can close critical gaps left by conventional detectors — identifying a dangerous condition while there's still time to prevent damage.

Early Fire Detection: Why it Matters

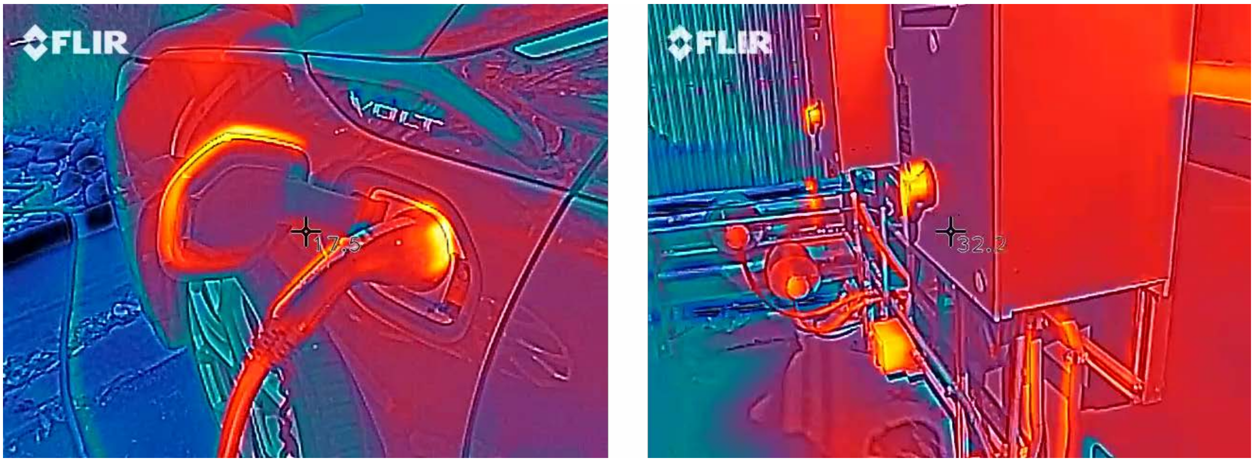
Typically, several overlapping systems are used to detect the outbreak of destructive fires in industrial settings. Each system may look for specific evidence that a fire has broken out: smoke, heat, or flame. A single solution would struggle as industrial conditions actively work against traditional fire detectors.

Data centers use high-velocity cooling systems in their dense server racks, which can disperse smoke particles too quickly to trigger smoke detectors. Smoke stratification, where hot smoke settles low in high-ceiling environments, can leave ceiling-mounted detectors entirely blind to a developing fire.

While each kind of detector has its strengths, they all detect post-ignition, after an active fire has already broken out. This is often too late. Even if a fire is detected and eventually extinguished, the resulting damage from soot, corrosive gases, and burning is often considerable, with the cost



1. Radiometric thermal image (left) taken by FLIR Edge Pro (right).



2. FLIR MSX (Multi-Spectral Dynamic Imaging) adds visual imagery outlines, words, numbers, and other high-contrast edge details to the thermal image for better image definition and accuracy.

of suppression-related collateral damage, e.g., water from sprinkler systems, potentially exceeding the cost of the fire itself.

Enabling Early Fire Detection with Thermal Imaging

Industrial fires most often start with incipient heating, where electrical resistance, mechanical friction, or chemical decomposition causes a localized temperature rise. This phase may last for minutes or hours before visible smoke or flames appear. Traditional systems typically miss this window entirely, but radiometric-capable longwave infrared (LWIR) thermal cameras can spot unusual hot spots and rising temperatures in time for a fire system to prevent an outbreak.

LWIR imagers offer a variety of other advantages over conventional options, such as being able to operate in dark or smoky conditions. The latest radiometric LWIR camera modules can be smaller than a dime, fitting inside miniature monitoring platforms and at a fraction of the cost of traditional infrared (IR) cameras *(Fig. 1)*.

There are limits to the capabilities of a standalone thermal imager, driven partly by cost, regulations, and physics. Cameras need a line of sight to the hot spot, meaning that large installations will require pan-tilt or multiple fixed cameras to cover an area.

Thermal cameras only “see” surface temperatures, meaning it might not detect a deep internal fault until heat conducts to the surface. Careful calibration prevents false alarms, and robust housings provide protection from harsh industrial environments.

The resolution of the thermal image can be critical to detecting hotspots in industrial environments. In a data center, a single loose electrical connection may be only a fraction of an inch. In power plants, thermal cameras may be mounted on gantry cranes or in massive halls, hundreds of feet from their target. If the camera resolution is too low, the energy from a tiny hotspot is “averaged” across a larger pixel area, resulting in an inaccurate, lower temperature reading that may fail to trigger an alarm.

Dual Thermal–Visible Imaging for Precise, Dependable EFD

To overcome the challenges of thermal-imaging-based EFD systems, OEMs have looked to combine radiometric thermal and visible-light camera sensors in a single imaging system. While the thermal sensor delivers the temperature data, the visible camera provides the context needed to differentiate hazardous conditions from harmless ones, e.g., a hot vehicle engine or sunlight reflection.

When a fire system triggers an alarm, security or safety personnel need actionable information immediately. The visible camera provides valuable contextual details: orientation of equipment, labels, indicators, personnel locations. This would enable maintenance teams to navigate fully prepared to potential fire. This is where dual-imaging shines, delivering a level of actionable thermal intelligence typically associated with more-expensive, higher-resolution camera systems.

How Dual Thermal–Visible Imaging Works

The thermal camera continuously scans the environment for temperature anomalies, producing a live temperature map (thermogram) of the scene *(Fig. 2)*. An unusual heat signature can trigger an alarm, even if no smoke or flame is present.

Radiometric-capable cameras can quantify temperatures, allowing integrators to configure an alarm to a specific threshold (e.g., 80°C > or +30°C / minute). This enables precise detection of early-stage events like an overheating cable, a smoldering bearing, or a battery cell going into thermal runaway.

Importantly, modern dual-camera systems often perform image fusion in real-time, overlaying the edges and details from the visible camera onto the thermal image to create a single, detailed picture.

Integration into Emergency Management Systems (EMS)

Dual thermal-visual cameras don't replace traditional detectors. Rather, they complement them in a facility's EMS. Thermal sensors offer early warning capabilities, and smoke/heat/flame detectors offer redundancy and code compliance.

Upon detecting a potential fire condition, the camera may send an alarm signal that triggers the same chain of events a smoke detector would: sounding sirens and notifying a monitoring center. The addition of visible light imaging means that imagery of intruders or other events can further enhance the overall EMS. Many systems can also archive images for post-incident analysis and regulatory compliance. Further integration may include automatic responses, cutting power to the affected equipment, activating venting systems, or releasing a fire suppression agent.

A key consideration for EMS integration involves meeting the technical requirements to ensure that the EMS workflow is reliable and responsive:

Data Quality and Standardization

Industrial installations are usually a combination of new and legacy systems. Successful integration requires the imaging system to send standardized alert events and video streams to any compatible security management software. Modern cameras support standard industrial protocols such as Modbus/TCP, MQTT, and ONVIF, but legacy emergency systems may use different protocols, requiring the use of protocol gateways (e.g., FieldServer) to translate.

Data silos are another common challenge, where inspection records, real-time heat maps, and maintenance logs exist in separate, disconnected databases that hinder the EMS when interpreting conditions. Accurate and complete metadata (timestamps, location IDs, temperature values) can prevent incorrect alert routing or automated responses.

Calibration and Consistency of Thermal Cameras

While thermal cameras provide accurate temperature data in many EFD scenarios, the consistency of those measurements relies on correct calibration. Current, load, and ambient conditions will all affect the measurements, so incorporating these conditions into the alarming criteria is critical.

Vendors with deep experience in thermal imaging will have a refined sensor calibration process, ensuring consistent temperature readings across thousands of units. This is a critical factor for operators with multi-site portfolios that demand a consistent and compliant standard of protection.

Scalability and Networking

Integrators need to ensure the system can handle simultaneous feeds and quickly identify the camera showing an alert. In large installations, multiple dual cameras will be networked together, making bandwidth usage a factor.

While lightweight, low-cost thermal imagers usually have lower resolution (e.g., 160×120 or 80×60), visible video will typically be HD or higher; streaming both continuously might tax networks and storage. Common solutions include only switching to high-rate streaming upon alarm, or preprocessing or filtering video streams at the edge.

Operator Training and Interface

The software and hardware interfaces presented to users (fire marshals, security staff) must be clear, backed up by documented standard operation procedures (SOPs). Does an alarm from a thermal camera trigger a full evacuation or preliminary investigation? SOPs will ensure responders know that a "pre-fire alert" is an opportunity to intervene before the sprinklers go off.

Use Cases and Applications

The extra cost and sophistication of dual thermal-visible EFD systems justify themselves in diverse high-stakes scenarios: preventing a costly data center outage, averting a factory inferno, or stopping a dangerous battery fire.

Data centers and server rooms: Downtime in data centers can cost thousands of dollars per minute. Performance throttling due to overheating could cause an entire AI training run to fail, costing millions. High-density, high-wattage electronics, from server racks to large uninterruptible power supply (UPS) systems, make fire risks ubiquitous, crucial faults difficult to spot, and windows for early detection short. A dual-vision system helps quickly verify which server or component is at fault.

Industrial manufacturing facilities contain numerous fire hazards: machinery with moving parts can overheat; processes that emit hot particles; and stores of flammable materials. In dusty environments like textile mills, smoke detectors might get clogged or be too slow, while thermal detection is unaffected by dust.

Energy storage and EV charging stations: Lithium-ion battery systems are notorious for fire risk. They can ignite spontaneously from internal faults, burn extremely hot, create toxic fumes, and can be difficult to extinguish. Early signs of battery failure include rapid heating (thermal runaway) often before any smoke is present. Thermal cameras systems at battery energy storage system (BESS) sites and EV charging stations can detect hotspots and trigger cooling measures or battery disconnects to avert an actual fire.

Oil and gas plants carry significant risks from complicated operations and a wide range of highly flammable materials. Effective fire protection helps prevent costly damage and ensures the safety of personnel during the production, storage, and transportation processes.

Warehouses and storage yards can be challenging for traditional fire detection, where a small ignition deep in a pallet rack or in a compost heap might go unnoticed by ceiling smoke detectors until it's massive.

Standards and Regulatory Considerations

Dual thermal-visual imaging-based fire detection is still relatively new, so compliance and standards are evolving. OEM integrators need to be aware of the regulatory landscape to ensure their dual-camera system performs to required standards so that authorities accept it. Designing with these standards in mind from the start will make it much easier for OEMs and their customers to deploy early fire-detection cameras with confidence.

Some common relevant standards include:

- NFPA 72 (National Fire Alarm and Signaling Code) is the main code governing fire-detection and alarm systems in the United States. It recognizes video-based fire detection (including both visible and thermal camera systems) but mandates a performance-based design approach.
- NFPA 75 (Standard for Protection of IT Equipment) focuses on data centers and similar facilities, emphasizing early detection and suppression because of the high value and fire sensitivity of IT equipment.
- NFPA 855 (Installation of Stationary Energy Storage Systems) recommends thermal monitoring as part of fire protection, and insurers often require it for large battery installations.
- NFPA 30, Flammable and Combustible Liquids Code, provides safeguards to reduce the hazards associated with the storage, handling, and use of flammable and combustible liquids.
- UL 2684 (UL Standard for Video Fire Detectors) is a testing standard specifically for video and thermal image detectors used in fire alarm systems, and especially relevant to OEMs who can assure customers that the device passed rigorous tests for resilience against fire, environmental conditions, and immunity to false alarms.
- EN 54 certification is a European standard for fire alarm and alarm systems in buildings, covering equipment such as smoke detectors, heat detectors, control units, and sirens.

Regardless of product certifications and code adherence, the local fire code and the authority having jurisdiction must make the final call on acceptance.

The Future of Advanced Analytics and Mitigation

Dual thermal-visual imaging systems represent a paradigm shift in industrial fire prevention and operational resilience. OEMs and system integrators are just starting to explore how integrated data streams can open new doors for machine learning and AI-driven analytics.

Each facility is different, but data analysis can allow operators to understand and adapt to the unique characteristics of their environment. Analyzing the "behavior" of heat sources over time can reveal detection of hard-to-spot fire patterns, improve false alarm mitigation, and even power preventative maintenance programs.

Maximizing use of thermal-visual imaging systems will continue to create new opportunities to make systems trusted and industrial facilities much safer.

Chris Posch has more than 20 years of experience creating thermal imaging cameras for numerous markets. He's currently the Director of Emerging Product Management at Teledyne FLIR OEM, where he's focused on working with automotive engineers and developers to deploy and test thermal sensors in ADAS and autonomous vehicle platforms as well as original equipment manufacturers integrating micro thermal cameras in professional and consumer products for emerging missions.

Learn more:

- Lepton XDS
- FLIR MSX (Multi-Spectral Dynamic Imaging)
- Long-wave Infrared (LWIR) Uncooled Camera Modules
- Firehouse.com