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# FIRE PROTECTION FOR LAUNCH FACILITIES USING MACHINE VISION FIRE DETECTION

Douglas B. Schwartz

Air Force Civil Engineering Support Agency
Tyndall Air Force Base, Florida

## INTRODUCTION

Fire protection of critical space assets, including launch and fueling facilities and manned flight hardware, demands automatic sensors for continuous monitoring, and in certain high-threat areas, fast-reacting automatic suppression systems. Perhaps the most essential characteristic for these fire detection and suppression systems is high reliability; in other words, fire detectors should alarm only on actual fires and not be falsely activated by extraneous sources. Existing types of fire detectors have been greatly improved in the past decade; however, fundamental limitations of their method of operation leaves open a significant possibility of false alarms and restricts their usefulness.

At the Civil Engineering Laboratory at Tyndall Air Force Base in Florida, a new type of fire detector is under development which "sees" a fire visually, like a human being, and makes a reliable decision based on known visual characteristics of flames. Hardware prototypes of the Machine Vision (MV) Fire Detection System have undergone live fire tests and demonstrated extremely high accuracy in discriminating actual fires from false alarm sources. In fact, this technology promises to virtually eliminate false activations. This detector could be used to monitor fueling facilities, launch towers, clean rooms, and other high-value and high-risk areas. Applications can extend to space station and in-flight shuttle operations as well; fiber optics and remote camera heads enable the system to see around obstructed areas and crew compartments. The capability of the technology to distinguish fires means that fire detection can be provided even during maintenance operations, such as welding.

## CURRENT FIRE DETECTION TECHNOLOGY

Fire detectors used today sense smoke, heat, or electromagnetic energy such as ultraviolet (UV) or infrared (IR) emissions. Only the latter type, also known as optical fire detectors (OFDs) are capable of speed-of-light sensing of flames; thus, they are employed where fast, remote sensing is required. Flames emit characteristic

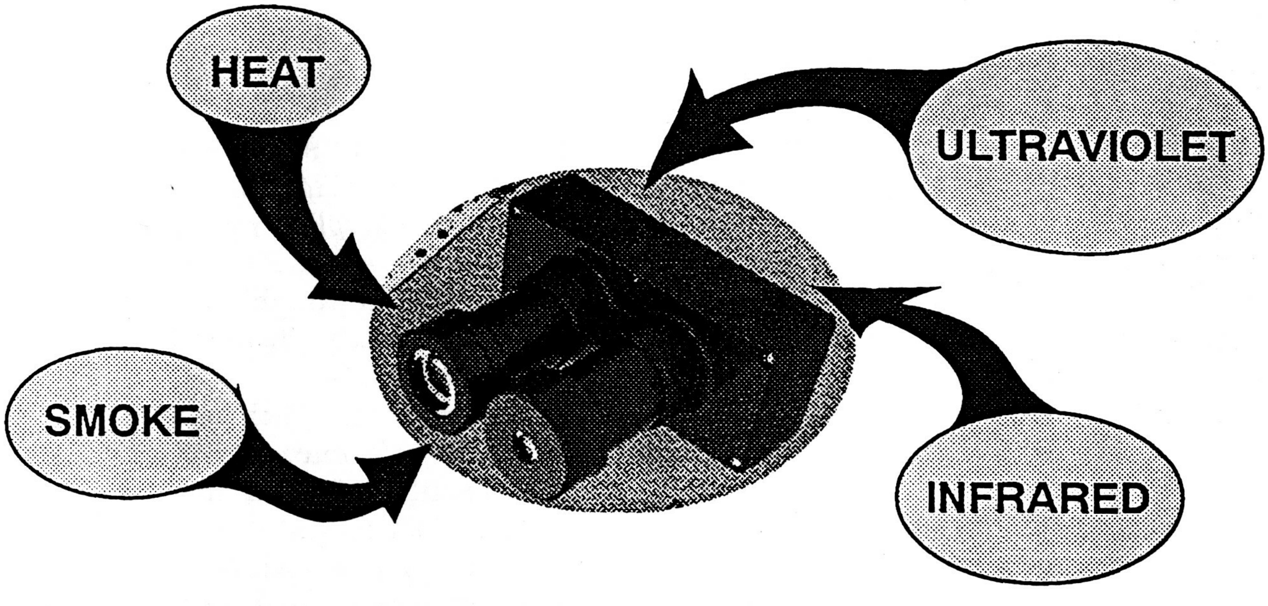


Figure 1. Conventional Means of Fire Detection (UV/IR detector illustrated).

electromagnetic emissions in particular bands, specifically the 0.18-0.24 micron band for UV and the 4.4 micron CO2 band for IR. However, any source emitting these frequencies will cause the detector to alarm. Ultraviolet detectors, for example, are commonly set off by reflected sunlight and arc welding. Infrared detectors can be set off by hot exhaust manifolds on powered support equipment, propane torches, and other heat sources. Many installations still use these single-band detectors, such as launch towers. In many cases, the inherent unreliability of this detection method has led to to disconnection from automatic suppression systems. To improve reliability, mulitispectral detectors have been introduced in the past few years, which require the presence of both UV and IR sources or two discrete, characteristic infrared frequencies. Although false alarms with this type have been greatly reduced, multiple sources of UV and IR radiation, often found in complex environments, can still cause false alarms. Detectors have also malfunctioned due to the presence of X-rays from testing equipment, vibration, and other hazards of the operational environment. The Civil Engineering Lab is completing testing of optical fire detectors against false alarm sources. The result will be a military standard to allow manufacturers to produce more false alarm resistant and environmentally hardened systems.

No matter how well optical fire detectors are constructed, the nature of ultraviolet/infrared detection implies certain fundamental limitations. Optical fire detectors trade off speed for accuracy; the faster the system is set to detect a fire, the higher the false alarm rate. OFD's are capable of detecting fires in less than 1/100 second, but are typically slowed to 3-30 seconds detection speed. This can be a significant delay where fast response time is needed, such as protection of heat-sensitive composite aircraft like the B-2 bomber. Since OFD's only sense the magnitude of absorbed energy impacting the detector, they cannot judge the absolute size of a fire; a small fire close up emits the same energy to the detector as a large fire further away. Intensity of UV or IR energy reaching the detector drops off rapidly with the inverse square law, leading to a maximum reliable range of about 120 feet. This is a serious limitation for coverage of large spaces, such as warehouses.

To circumvent these limitations, an effort was initiated in 1990 to incorporate image processing technology into a new type of fire detector. Machine vision fire detection actually "sees" the fire in the visible spectrum and applies numerous and flexible criteria to judge the presence of fire. The detection process has been designed to assure immunity to all known sources of false activations while reliably and rapidly detecting visible flames. Furthermore, the nature of the system means it can be adapted to visually sense non-fire threats, such as fuel vapor clouds.

The front end of the system is a solid-state video camera, which uses a CCD (charged-coupled device) to convert light into electronic information. The CCD consists of a square grid of picture elements (pixels) typically 512 on a side, or over 250,000 pixels total. This chip can resolve a one square foot fire at 100 feet. The intensity of red, green, and blue light impacting each pixel is sequentially input into computer memory, which builds up a "virtual image" or frame which can then be analyzed. This takes place every 1/30 second.

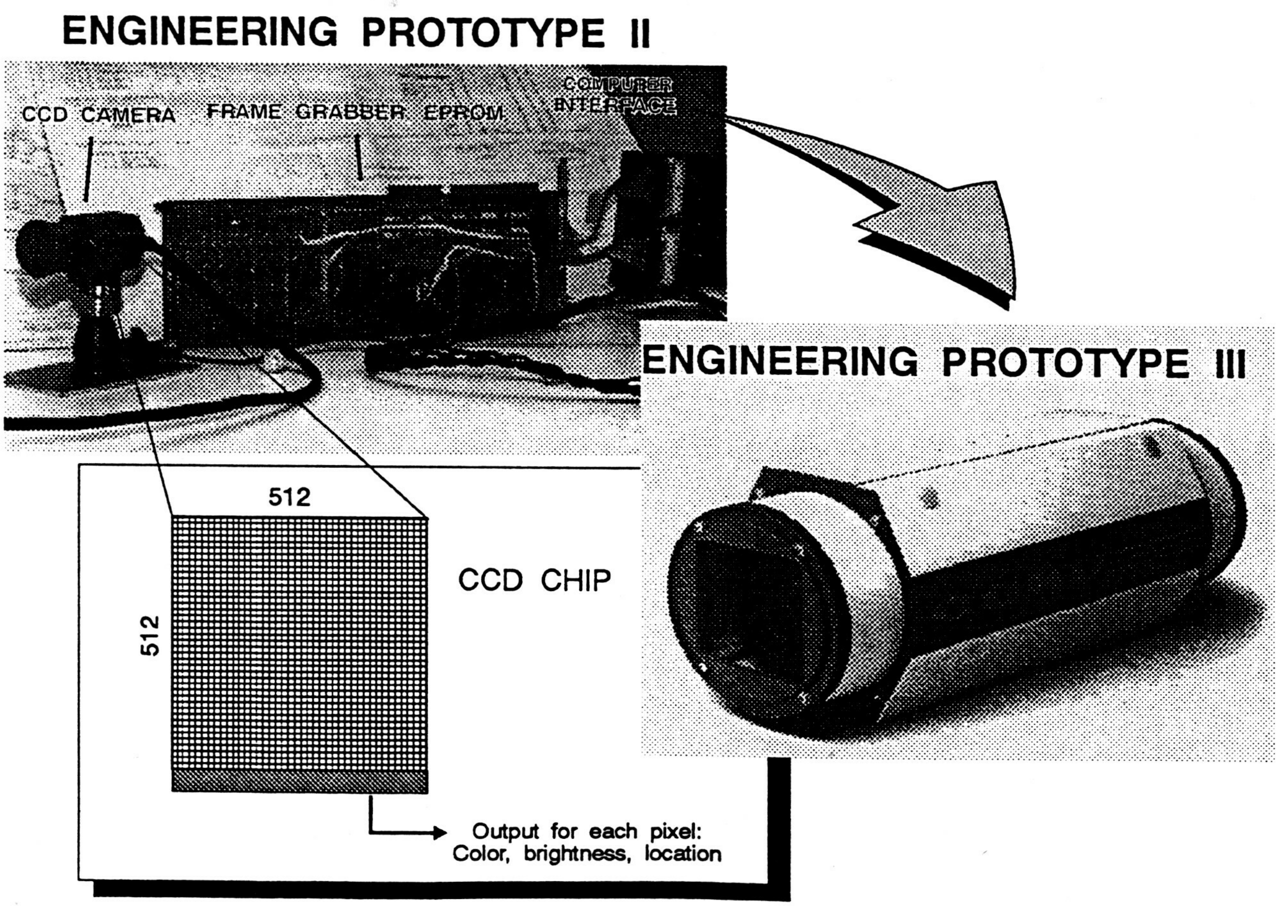


Figure 2. Machine Vision Hardware.

Pixels are checked for minimum brightness (intensity) and color within red, green, and blue parameters. Succeeding frames are compared, revealing changes in color from frame to frame, behavior of the edge of the object, and growth rate. Actual fires exhibit rapid color changes from frame to frame, have highly variable edges, and tend to grow outward from a starting point.

Size of the fire is computed by counting the pixels meeting the "fire" criteria. Where installed in a fixed setting, such as a launch tower, the system will be calibrated at installation to relate position within its field of view to a particular size. Thereafter, the pixels across the base of the fire can be summed and actual size computed from the number of pixels from the lower edge of the field of view. Portable or mobile installations will use two cameras on a known baseline for range estimation.

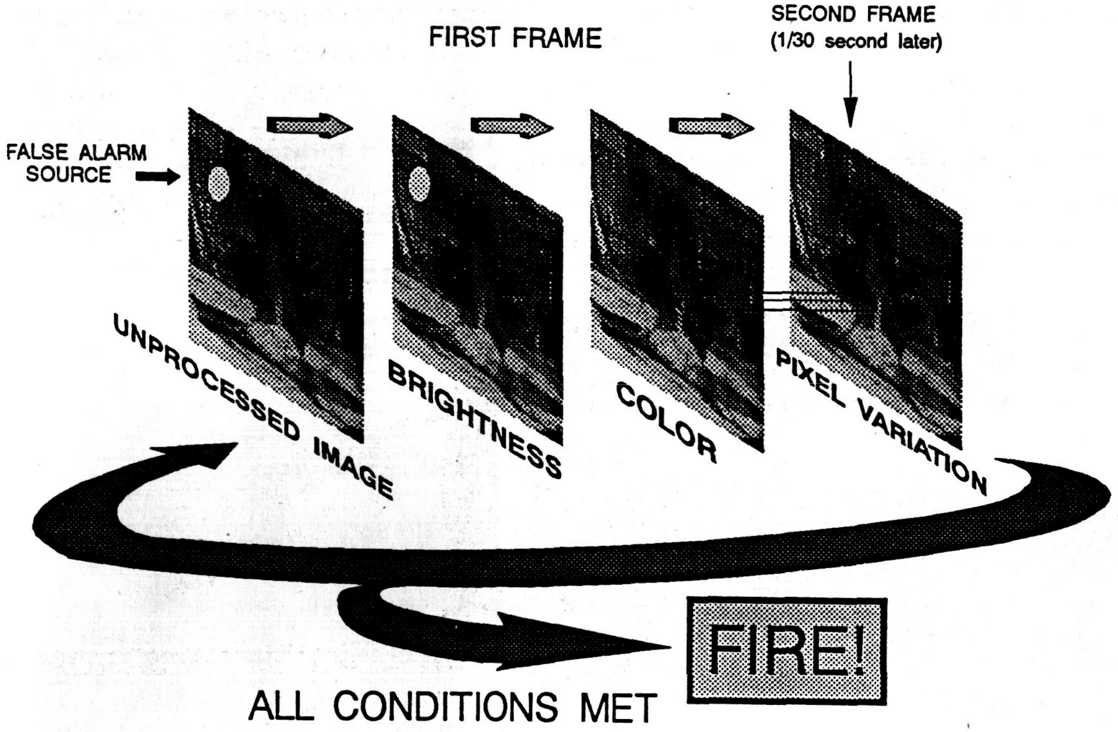


Figure 3. Fire Decision Criteria.

Knowledge of the actual size and growth rate allows determination of the degree of threat of a particular fire. A detection and suppression system can have a selection of possible responses depending on the threat, instead of the current all-or-nothing approach. In a typical Air Force application, for example, machine vision detectors would be linked to an automatic suppression system capable of dispensing tens of thousands of pounds of firefighting foam onto a hangar floor. A small rag fire in a corner of the hangar would typically trigger optical fire detectors to release this massive quantity of agent, requirin ; a costly cleanup for what could have been extinguished easily by hand. The machine vision detector can be set to only sound an alarm for such small, non-growth fires, to alert personnel in the area as well as the fire department. If the fire were to exceed a certain size, or if growth rate became high, the suppression system would be activated. More advanced systems could have directional nozzles for a localized response, avoiding unnecessary cleanup and getting more agent on the actual fire.

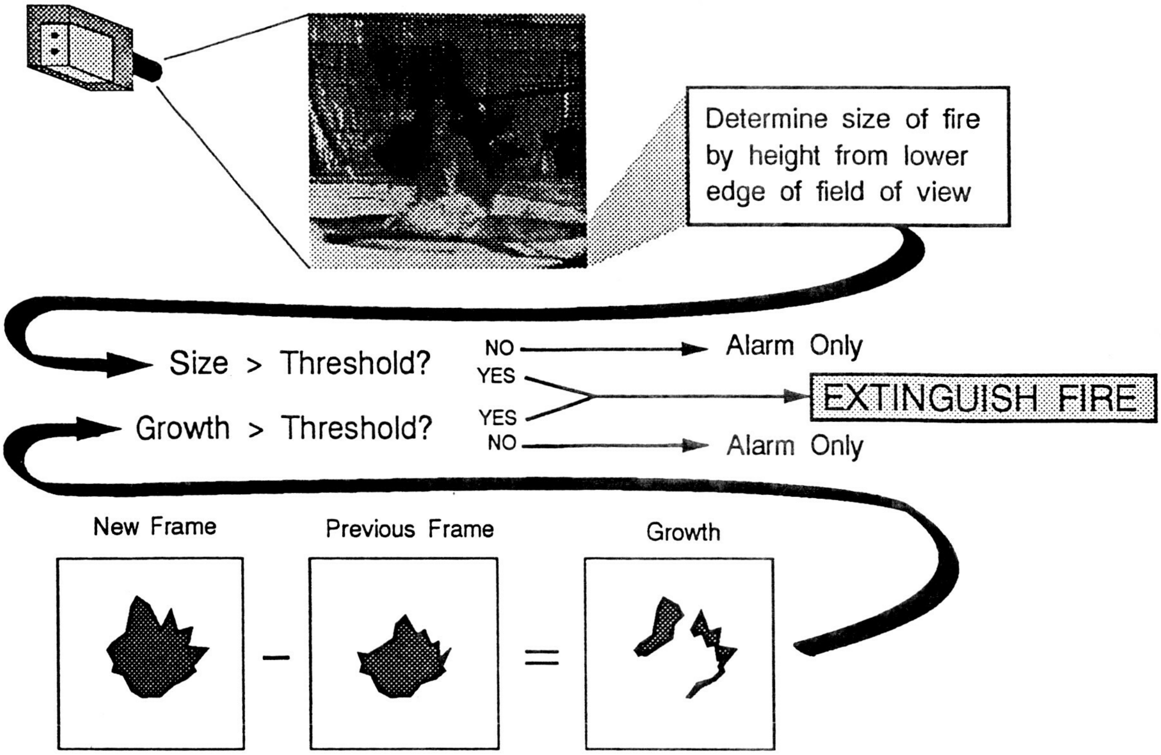


Figure 4. Fire Suppression Decision.

## COST AND AVAILABILITY

The hardware components of the system, including the video camera, image processing hardware, and microprocessor, are all available "off the shelf." This drives down cost and technical risk. Current cost of the components is about $2500 and is expected to drop, following the general trend of the small computer industry. New components have become available even during the development process. A new image processing board is being incorporated which will eliminate the need for a separate controlling microprocessor, reducing parts count and cost. The final prototype will consist of the camera, power supply, and one or two circuit boards containing a microprocessor, memory, and all the "rules" for fire detection and decision making. Time for this prototype to make a fire/no fire decision is 1/10 second. Unlike optical fire detectors, speed of detection is unrelated to accuracy; faster times can be achieved, if necessary, through use of a faster microprocessor.

## POTENTIAL NASA/SPACE INDUSTRY APPLICATIONS

Machine vision fire detection "knows" what a fire looks like through algorithms embedded in programmable hardware. Because the criteria used in these algorithms is precisely known, the algorithms can be updated to take into account additional threats or false alarm sources tailored for a particular environment. One example, especially applicable to construction and maintenance environments, is to account for luminous sparks, such as from welding. A spark will move rapidly from place to place, unlike a fire, and will have a particular shape. Visual characteristics such as these can be more precisely defined than intensity of radiation sources, which optical fire detectors rely on. In fact, the algorithms can be programmed to identify any visible object with sufficient contrast. For example, vaporized fuel from inadvertent leaks or releases often produces a visible "cloud." Instead of slow-reacting sampling detectors or line-of-sight sensing with restricted coverage, MV detection could be programmed to sense the visible vapor.

Numerous NASA facilities use single-band UV or are scheduled to upgrade to more advanced UV/IR detectors, including shuttle and space station processing bays in the Vehicle Assembly Building, the payload changeout room and transfer arm at the launch pad, and fuel storage and handling facilities. The known limitations of these detectors drive up cost and reduce utility. For example, UV/IR detectors are limited in range because the method depends on the magnitude of emitted energy. The high bays in the VAB are vast spaces over 500 feet high and 400 feet on each side. The UV/IR detectors used are calibrated to detect a 1 square foot fire at 45 feet; thus, many detectors are required to cover this area, at a correspondingly high cost. Machine vision detectors using high-density CCD sensors on the market would have over four times the range. Furthermore, only one computer/processor is needed for up to six cameras, decreasing cost. MV detectors are proving effective where visible flames are involved; near infrared capability would enable the system to detect otherwise invisible hydrazine and hydrogen fires.

For in-flight applications, Machine Vision is a lightweight, reliable alternative. The space station, with its considerable inhabited spaces, will especially require automatic fire detection. One processor could cover a large area, with fiber optics feeding visual information from computer cabinets, equipment enclosures, and other confined areas. A similar concept is scheduled to be developed by the Air Force to protect engine and other internal compartments on the F-22 fighter.

MV detection is a far superior alternative to the single-band fire detection sensors now in common use and has considerable advantages over even the most recent UV/IR detectors. The system is currently in its second prototype stage and has undergone periodic field tests against actual fires and false alarm sources. At the end of 1992, final prototypes will undergo full scale validation. Performance will be evaluated against UV/IR detection for incorporation into a major Air Force upgrade of hangar fire protection systems. The technology will also be applied to development of portable, self-contained fire detection and suppression systems and numerous other applications.

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