Emergency response chemical detection using passive infrared spectroscopy

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Emergency first responders can detect and identify chemicals with passive instruments mounted on an aircraft sent to monitor the scene.

The U.S. Environmental Protection Agency uses passive remote infrared spectral sensors mounted on a small aircraft to monitor and map the downwind hazard of the chemical plumes from train car derailments, chemical plant fires, and explosions. The agency uses multi- and hyperspectral infrared sensors at emergency-response sites to detect, identify, and map the infrared spectral absorption and/or emission features of the chemical vapor. To deploy the specially equipped aircraft, a local incident commander makes a request through the EPA’s on-scene coordinator network. A pilot then flies the plane over the emergency site while the sensors scan the area. The systems collect images and spectral data in the 3−5μm and 7−14μm atmospheric windows.

The EPA program, named ASPECT (airborne spectral photometric environmental collection technology), is the nation’s only always-on-call emergency response system capable of mapping a chemical-plume hazard. The aircraft’s infrared systems detect and track vapor plumes via two spectral systems. The first sensor is a multispectral, high-spatial-resolution infrared imager that creates two-dimensional images. An operator then calls upon data-analysis technology to process the images, which contain various spectral wavelengths, into images that indicate the presence of a particular chemical species. Each series of pixels on the analyzed images is recorded along with its global positioning system location. The data is corrected for the aircraft’s pitch, yaw, and roll. The result is an accurate surface map that standard geographic information system software can display. The system also collects and geo-corrects high-spatial-resolution visible images for overlay on the infrared image, the chemical plume, and the visible image of the site.

The airborne IR imager is a model RS-800, multispectral IR line scanner (Raytheon TI Systems, McKinney, TX). The basic system design couples a one-dimensional object plane with a scanner. The refractive scan element is constructed from a gallium-arsenide double-dove prism. The prism rotates at 30Hz and scans the photoconductive mercury-cadmium-telluride array across an unobstructed 60° field of view. The IR line scanner has 32 cryogenically cooled detector elements, with optical filters bonded to individual detectors to restrict their spectral response to the midwave infrared (16) and the longwave infrared (16) with a limiting F-number of 1.18. The line scanner’s unobstructed 60° field of view equates to an instrument field of view of 0.057° producing 1500 pixels. This results in a pixel size of about 1.5×1.5 feet at an operational altitude of 2200 feet.

The second infrared instrument, a high-throughput Fourier Transform Infrared Spectrometer (FT-IR), can be used to collect a higher spectral resolution of the infrared signature from a specific plume location. This instrument collects spectral signatures with a selectable resolution between 0.5 and 32

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Figure 2. (left) The IR image shows an ethylene plume location; (right) the passive IR spectrum collected over the plume location indicates the absorption feature of ethylene.

Using the passive remote infrared spectral sensors presents one significant challenge: data analysis. Because the aircraft is in motion, no reference background spectrum exists. The data analysis used for the ASPECT aircraft requires special digital filters and automatic-detection pattern-recognition methods. The digital filtering removes any residual background spectral contribution and also removes potentially interfering higher frequency signatures such as atmospheric constituents. Each spectral signature possesses a specific bandwidth and band location. The digital filter is designed with a specific dynamic range for attenuating the out-of-band signals while preserving those in band. The use of finite impulse response filters has been shown to effectively extract a variety of vapor target signatures. More recent advances in digital filter design have resulted in the matrix-filter approach to address dynamic-range limitations. After digital filtering removes unwanted background signatures, the user applies pattern recognition to those remaining. Several methods for this have been previously described in the open literature. The primary one applies an automatic classifier, then separates temperature and emissivity. This is the piecewise-linear discriminant analysis method, which extends linear discriminant analysis for solving nonlinear classification problems. The PLDA discriminant is a series of separating surfaces that, when combined, form a surface for classification. PLDA discriminant coefficients are developed during a supervised training process using data-containing patterns known...
to contain the compound of interest. The patterns (spectra) are placed in a training set to decide the placement of the multiple linear surfaces. The initial discriminants are calculated using a Bayes classifier. The resultant discriminants are usually trained to minimize false alarms. Since the spatial resolution of the imager is extremely high, these methods, which use multiple pixels, can be used to further reduce false alarm rates.

Since August 2001, ASPECT has been deployed more than 60 times. It has been used in high visibility emergency responses including the 2003 California Wildfire, the 2003 space shuttle Columbia recovery, and the 2005 responses to Hurricanes Katrina and Rita. The aircraft, based immediately south of Dallas, TX, can be deployed quickly (wheels up within one hour) and arrive on an emergency response scene in a timely manner.

In October 2005, a methylacrylate production facility in southern Texas, housed near ethylene feed stock, caught fire. The aircraft scanned the area around the hazard and operators soon had data-analysis results. The spectrum collected and infrared imagery obtained are shown in Figure 2, in which a plume of ethylene (in red) can be seen being released away from the fire (shown in white, indicating an area of high temperature).

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