Standoff Wide Area Detection of SF_6 by Means of a Passive IR Imaging Spectrometer

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Abstract

A new, passive infrared instrument based on the proven technology for remote detection of military chemical agents is tailored for sulfur hexafluoride (SF_6) leak detection over a 10 x 14 degree field of view. This rugged and reliable instrument has been field-tested for several months and a detailed use scenario has been developed for use against machinery, sky, or terrain backgrounds. The system provides rapid, straightforward examination of large areas from ranges of 15 feet to 100 feet and can work as close as 6 feet. Under realistic conditions, leaks as small as one pound per year can be detected. Additional statistical real-time data processing techniques will further assist the operator in evaluating leaks.

Introduction

Block Engineering has worked on SF_6 detection for years; it is used as one of several IR target simulates for chemical agents or nerve gas. The approved military technique for standoff detection is based on Block Fourier Transform InfraRed (FTIR) technology developed during the past 35 years.

The detection algorithm used to indicate the presence of SF_6 was developed by MESH, Inc., and refined for the Block Model 100 FTIR Spectrometer (Figure 1) in a battlefield scenario; the typical gas-insulated substation or plant is a much simpler detection environment by comparison. The algorithm has been refined and perfected by MESH during many years for more stringent purposes, and relaxation of some constraints may allow for even greater sensitivity. Detection software exists for all the military applications and is presently being developed for some of the toxic industrial chemicals.

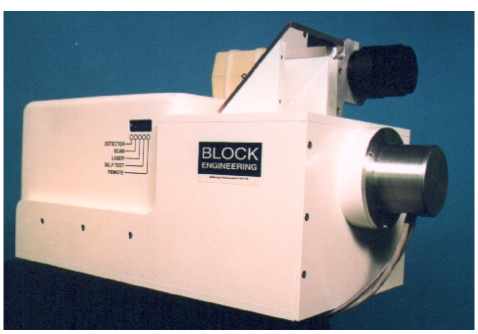

Figure 1: I-Spec, SF_6 Camera

Block was approached by EPRI and several others to create a user-friendly, totally eye-safe system for cost-effective remote/standoff leak detection. Here, cost-effective means the ability to search larger areas from several positions and locate gross leakage in a minimal amount of time. Pinpoint location of the leaks to within a few centimeters would subsequently be done using alternative instruments after the leaks were generally located. Pinpointing leaks at the high tension ends of bushings and insulators would wait for power shutdown.

A typical field of regard (FOR) from one location is typically 17 x 25 feet at 100-foot range. Although the system has no minimum range, individual spatial resolution elements can be as small as 2 inches squared at a 6-foot standoff distance.

The typical use scenario involves setting the unit on a tripod at a 50-foot to 75-foot range and scanning the area for one or two minutes. Detection data are displayed during the scanning period, and averaged results are displayed at the end of a measurement sequence. The unit is then moved to another location for repeated collection so that leaks that are masked by intervening equipment may be seen. The time for a complete setup/takedown and move to a new location typically takes less than five minutes. Integrating for one or two minutes offers the advantages of increased sensitivity and better localization of the leak.

Block is currently developing automated statistical display techniques to aid the user in detection and interpretation of the data. Initial results are very promising, and the equipment performs well as a tripod-mounted device in the field.

All the raw data (spectra, picture, and overlay) are stored in the portable computer and may be printed, in color, or stored for later inclusion in a comprehensive report.

Technology

The I-Spec SF_6 camera utilizes a very sensitive FTIR spectrometer coupled to a rapid precision scanning mechanism that rapidly steps its instantaneous field of view over a 14° wide by 10° FOR in one second (Figure 2). It is co-aligned with a high-resolution TV camera that presents a grayscale picture of the equipment. After each of 140 spectra is obtained, it is processed by the MESH recognition software, and the results are interpreted by Block software for display. The overlaid grid of spectrometer results is color-coded to give an approximate concentration of SF_6 gas within that pixel. Data are available in pictorial form on the monitor one second later. It is possible to improve sensitivity by accumulating several frames and averaging the data. This process is selected and controlled by the operator.

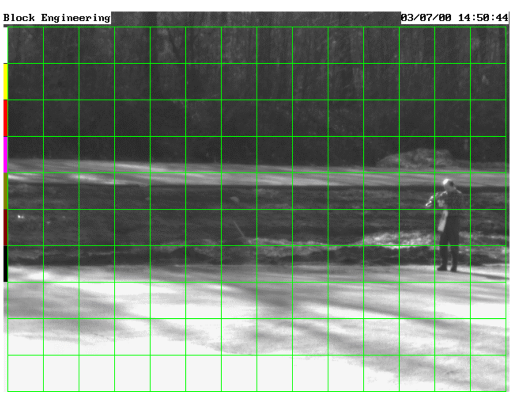

Figure 2: I-Spec SF_6 Camera Display

Because the I-Spec is based on a general FTIR spectrometer, it can detect any IR-active gas or vapor in the long wave IR atmospheric window simply by changing the recognition software in the system. Short-wave IR and wide-band IR versions are available on special order. It is also capable of detecting more than one gas/vapor simultaneously, which has broader application in the chemical industry. The system does not look at only one spectral band but makes use of the entire spectrum of the target gas so that its unique signature is not mistaken for any other species. In the SF_6 leak detection application, one advantage of this technique is to minimize the occurrence of false positive data when interfering agents are present.

The system works on the small positive or negative temperature contrast present between the gas and the background. The gas is almost always hotter or colder than the background—whether that be sky, terrain, or mechanical equipment housings (Figure 3). Typical sky temperatures, for example can be from 20 degrees to 70 degrees colder than the air temperature at sea level. A cold, clear, night sky exhibits even greater extremes. For passive instruments, the proportion of the pixel (IFOV) filled by the gas is also relevant. More precisely, the technique is sensitive to the total number of relevant molecules in the path between the background and the instrument. We call this the concentration length or CL.

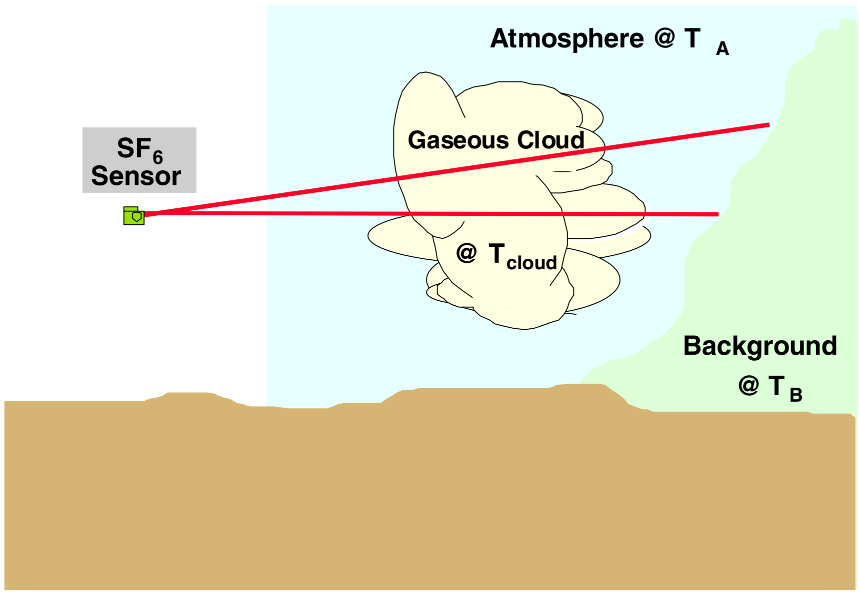

Figure 3: Passive IR Detection

Because it is based on mature field instrument technology, the I-Spec SF_6 camera is rugged, reliable, and operational. Several instruments are fielded and being demonstrated for a variety of industrial applications. Block is presently working on second-generation techniques to enhance user friendliness and make the data interpretation even more obvious and intuitive. Continuing improvement is cross-fertilized by our work in remote chemical detection for a variety of other government and potential industrial customers.

The heart of I-Spec is a rugged, reliable, field-proven instrument—the Block Engineering Model 100 field spectrometer. The Model 100 "engine" was developed more than six years ago and approximately 30 units have been fielded. It has received excellent reviews from military users and has just gone through a series of indoor and outdoor detection tests by the U.S. government's Dugway Proving Grounds, where its effectiveness against toxic agents has been demonstrated at several kilometers. Because the I-Spec is just a Model 100 with a front-end scanner, recognition software, and a television camera added, it has the same reliability as the Model 100.

Specifications

Specifications for the system are listed in Table I. The total system consists of the optical head, interface electronics, and portable computer. The system is currently configured to run with line power, with universal worldwide power supply, or on battery power. Cable between the optical head and the computer may be 10 feet to 100 feet.

Table I

Field of regard (FOR, 140 pixels)	10 x 14 degrees (175 x 244 mRadians)
Instantaneous field of view, (IFOV, for one pixel)	1.5 degrees (26 mRadians)
Spectral resolution, wave numbers	16 cm-1
Spectral scans per second	140 (one full frame)
Sensitivity	3 ppm-meter @ • T=8.1C
Full frames per second	1
Data reduction time to display	1 second
Data storage and archive	Std. PC, portable
Software	Windows 95 or later
Typical file size	300 kB per frame (approx.)
Overall size (optical head)	9 x 7 x 16 inches
Weight (optical head)	<15 pounds
Power (system)	100-240 V DC-60 Hz, <300W

Sensitivity

The I-Spec is totally self-calibrating and self-standardizing. Determination of absolute sensitivity to various compounds has been studied carefully. For accurate sensitivity determination, one must know the total number of target gas molecules in the path and the temperature contrast between the target gas and the background. This can be done in a sealed chamber or approximated outdoors with very large vapor clouds and a sampling sensor grid. For small clouds or leak plumes outdoors, such calibration is not feasible and a more empirical approach is needed.

After carefully calibrating the I-Spec against known, traceable blackbody sources, we employed the equipment shown in Figure 4 to determine detection limits. Block built the test chamber for nontoxic gases, and the partial pressure and temperature of the gas can be controlled. The exact path length through the chamber is also known. We provide a known temperature background at one end of the cell and observe the cell, which fills one or more pixels, from the other end. This can be done indoors or outdoors. It is from this type of measurement that our concentration length (CL), 3.1 ppm-m sensitivity, number is derived. The response to other gases can be derived by standard spectrometric techniques or measured directly.

Because the relationship between leak rate and CL is completely dependent upon the plume geometry, which is in turn dependent upon wind speed and local turbulence effects, there is no simple way to relate the two. We therefore configured a simple experimental apparatus to release known flow rates of SF_6 from a small aperture under a variety of realistic outdoor conditions (real wind shear and micro-turbulence).

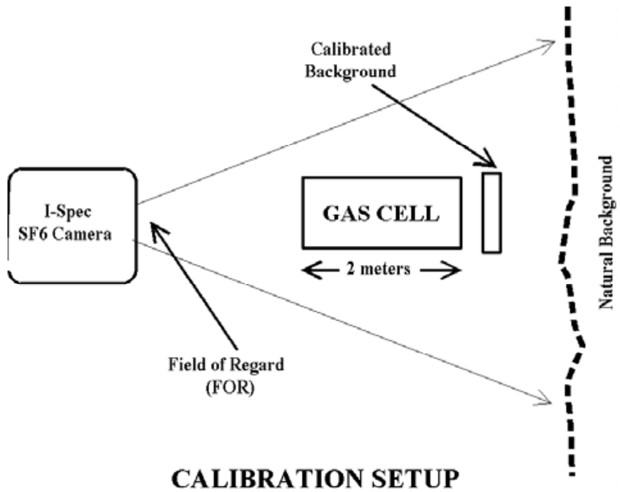

Figure 4: Sensitivity Calibration

The contrast, or • T, was measured on a bland surface well behind the leak. For tests against sky background, the effective temperature of the sky is derived from the closest blackbody curve match.

Using this technique, we established some early benchmark leak detection rates for one-second measurements. The system detected leak rates of 10#/year of SF_6 at a • T of 8°C in one second. Generally, the sensitivity will improve in proportion to the square root of the observation time. For a two-minute (120 seconds) period, the minimum detectable leak will be reduced to 1#/year if the wind speed, local turbulence, and temperature contrast are reasonably constant over the short time period. Measurements are being made with a revised averaging approach and should confirm this.

Results

Note that all data shown are from only one frame taken over a duration of only one second. Averaged data will be published as soon as they are available.

Typical results for test releases are shown in Figures 5 and 6, which show a short release in a prevailing wind from the right side of the frame. Note particularly the character of the cloud as it moves off in the wind direction after the source has been stopped. These figures represent single, one-second frames of data that are available in real time on the display.

Figure 7 shows a calibrated flow release against a sky background, and Figure 8 shows typical data from an actual field test in New York. In both cases, no attempt was made to integrate for more than one second (1 frame) to improve sensitivity.

Figure 9 displays another data format that can be useful for more scientific analysis of the data, should that be required. It presents actual spectra obtained for several sequential frames and any frame's or pixel's data can be enlarged for closer study by simple keyboard and/or mouse controls. All such data are retained in the system (if desired) in the event that additional analysis is desired on the raw data itself.

Planned Work

Pending our evaluation of the various market applications for which the I-Spec SF_6 camera is useful, Block plans to incorporate the following features into the next generation of instruments. All these features can be retrofitted into the existing instruments.

1. Optimize the statistical software so that leak location under turbulent conditions is more easily established.

2. Incorporate a duplicate display in the optical-head-mounted viewfinder to allow operation without reference to the computer until printout or other manipulation is desired.

Summary

The camera works against any background, including the sky and does not need a backdrop.

The system is user-friendly, with the composite image showing detected gas concentrations overlaid on easily interpreted video.

The camera has a large field of view and can move in for close-ups as near as 6 feet (2 meters) for better localization of leak location.

The camera is totally passive and therefore eyesafe under all operating and/or fault conditions.

The camera is capable of detecting a variety of gases -- not just SF_6.

Under the recommended use scenario, major leaks can be detected over an 18 x 25 foot area from a 100-foot standoff distance in just a few minutes.

Present performance indicates further increases in sensitivity are practical and further automated leak location can be achieved.

Acknowledgement

The authors and Block Engineering wish to thank Dr. Sherry and Dr. Larry Grim of MESH, Inc., for their very rapid and continued responsiveness in tailoring and optimizing the recognition software for use in the I-Spec SF_6 camera system.

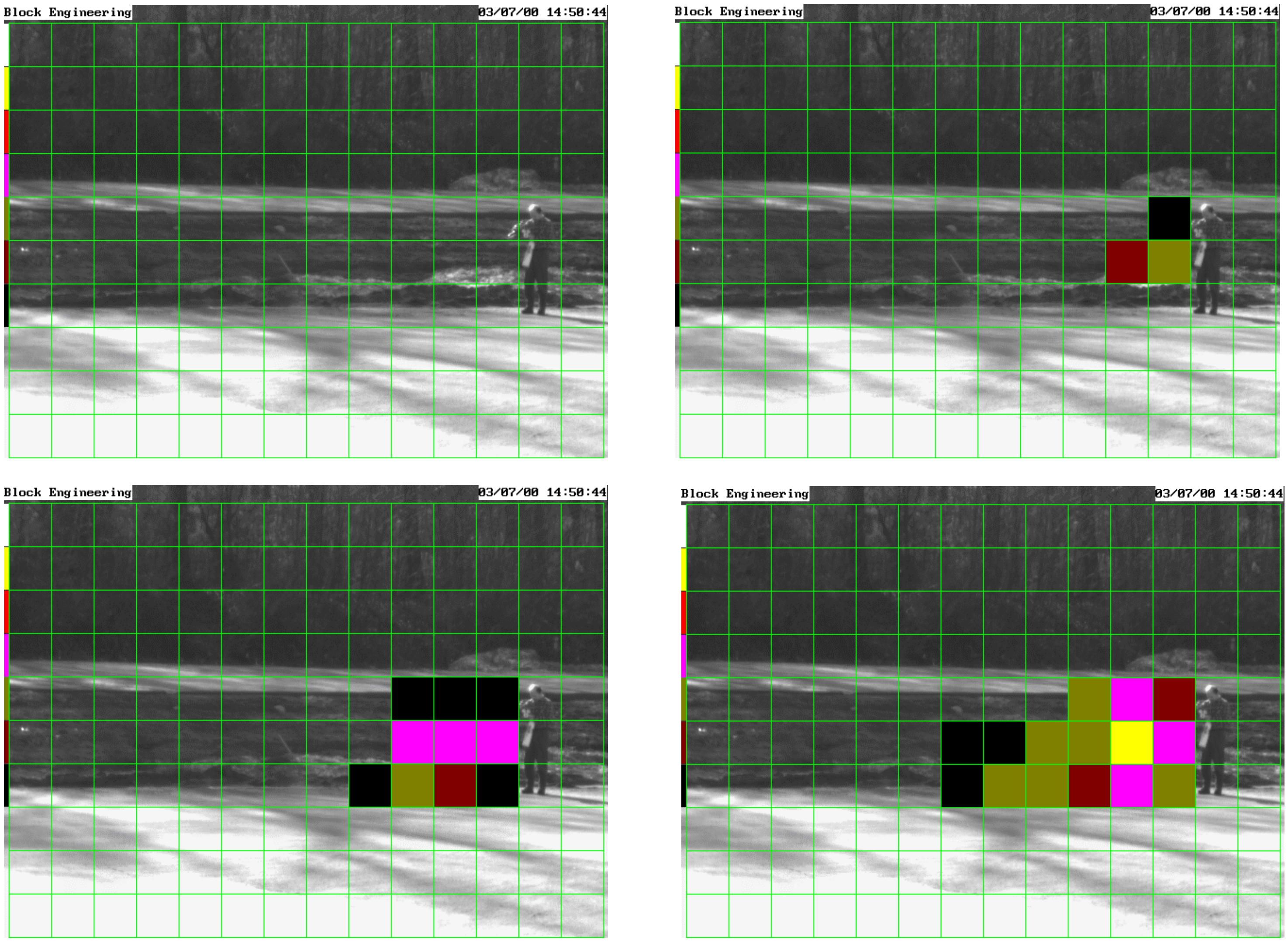

Figure 5a-d: Test release of SF_6 in moderate wind; range is 30-50 feet

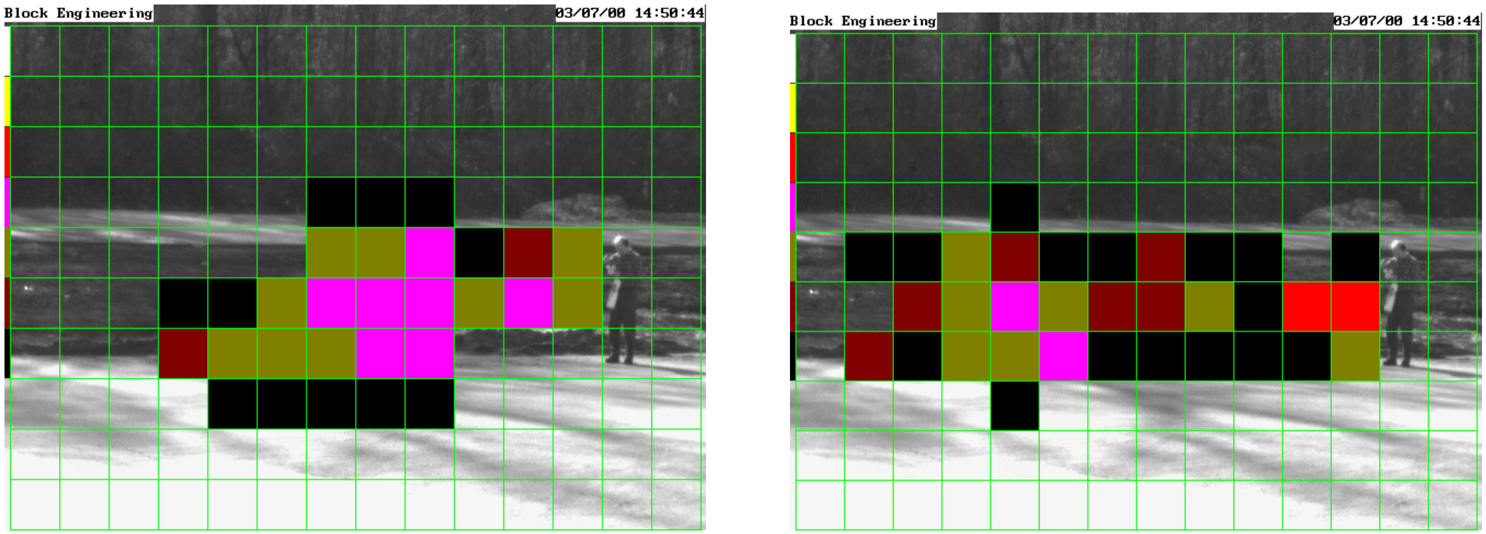

Figure 5e, f: Test release of SF_6 in moderate wind; range is 30-50 feet

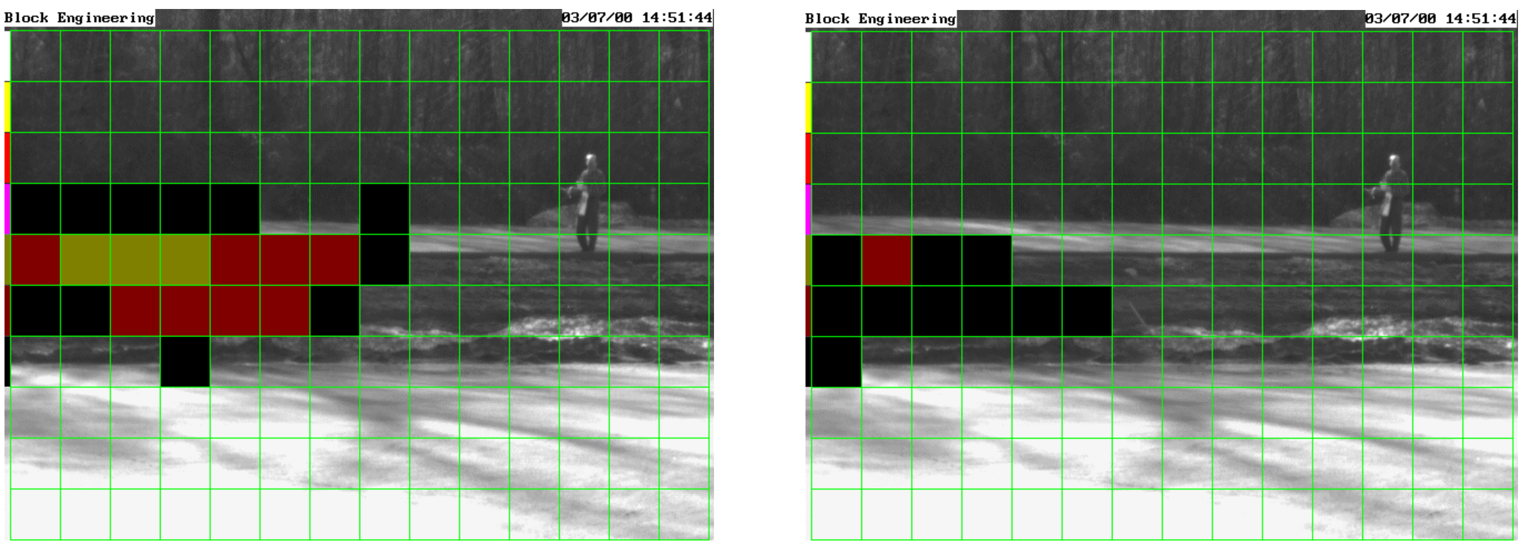

Figure 6a, b: Another test release at 75-foot range ending, showing cloud drift

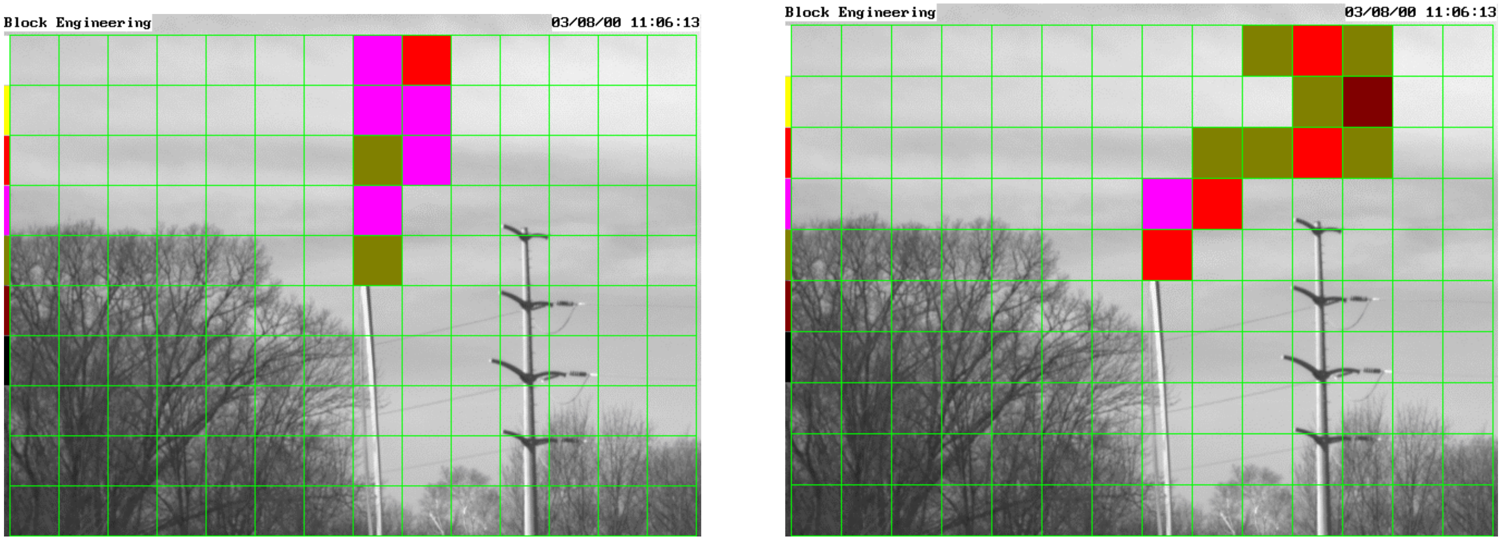

Figure 7: Calibrated release against cloudy sky background

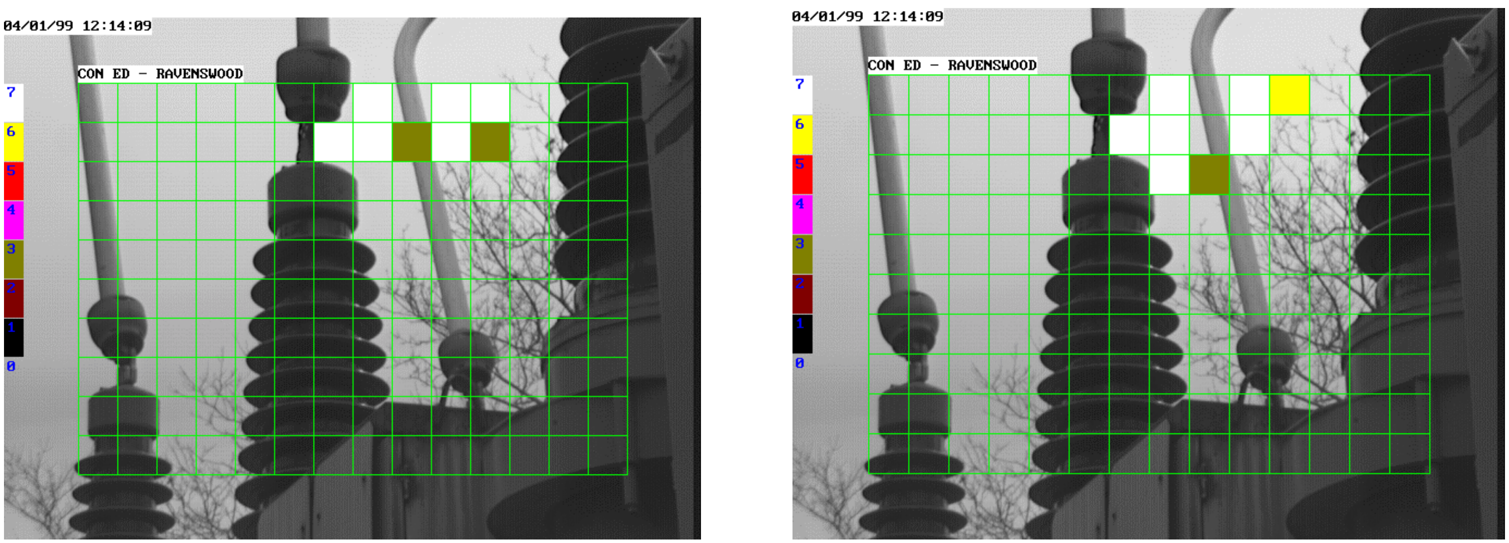

Figure 8: Data from on-site field test in New York

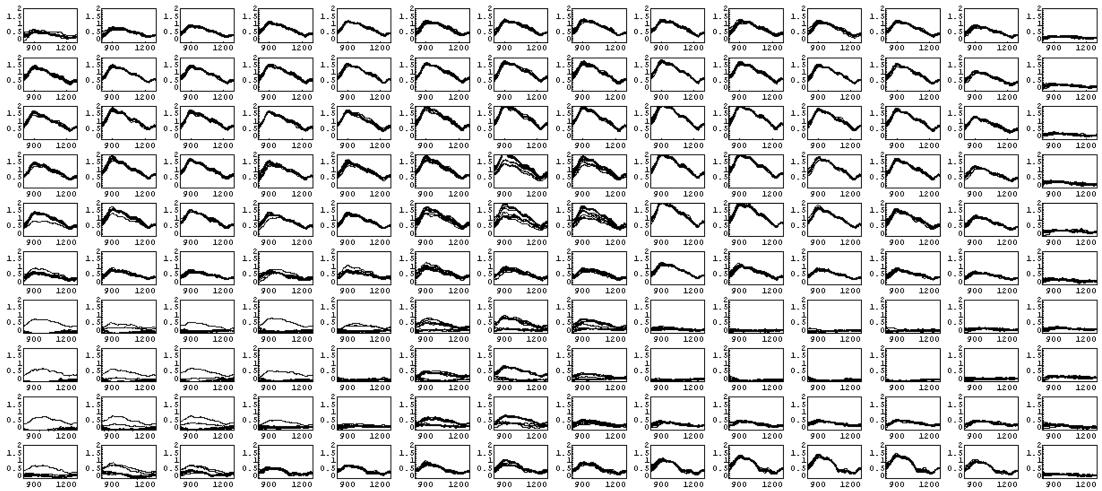

Figure 9: Alternative data display for scientific analysis of spectra. Each box contains overlaid spectra for each pixel from several full frames of data. Mouse and keyboard controls allow enlargement and selection of any particular pixel and frame for more detailed study.