CURRENT GROUND-BASED LWIR HIS REMOTE SENSING ACTIVITIES AT DEFENSE R&D CANADA - VALCARTIER

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ABSTRACT

Recently, DRDC Valcartier has been investigating novel ground-based longwave hyperspectral imaging (HSI) remote sensing techniques. Specific projects include the development of a new ground-based sensor called MoDDIFS (Multi-Option Differential Detection and Imaging Fourier Spectrometer), which is a leading edge infrared (IR) hyperspectral imaging (HSI) sensor optimized for the standoff detection of explosive vapours and precursors. The development of the MoDDIFS sensor is based on the integration of two innovative technologies: (1) the differential Fourier-transform infrared (FTIR) radiometry technology found in the Compact Atmospheric Sounding Interferometer (CATSI) previously developed by DRDC Valcartier, and (2) the HSI technology developed by Telops. The MoDDIFS sensor will offer the optical subtraction capability of the CATSI system but at high-spatial resolution using an MCT focal plane array of 84×84 pixels. The MoDDIFS sensor offers the potential of simultaneously measuring differential linear polarizations to further reduce the clutter in the measured radiance.

1. PASSIVE STANDOFF DIFFERENTIAL DETECTION AND CATSI

The CATSI sensor [1,2] is a passive infrared system designed for the standoff detection of chemical vapours. Its differential detection capability provides two unique features for a field-deployable instrument. First, CATSI, as shown in Fig. 1A, maintains a constant calibration, thereby providing reliable quantitative measurements over a long period of time. Secondly, it can perform the real-time optical subtraction of the background signal from the target signal without the need for extensive calculations. Supported by unique acquisition software (GASEM) [3], CATSI is capable of on-line chemical vapour identification based on the spectral emission signatures of gases measured in the infrared region from 7 to 14 µm.

Current methods for the passive standoff detection of chemical vapours by FTIR spectrometry are often limited by the large clutter IR emission from the intervening atmosphere and background. In order to mitigate the clutter impact and reduce the processing burden, the differential detection approach offered by CATSI measures the IR radiation from a target scene which is optically combined onto a single detector out-of-phase with the IR radiation from a corresponding background scene, resulting in the target signature being detected in real-time void of significant background clutter. During the past ten years, the sensitivity and accuracy of the differential detection approach with the CATSI sensor has been well established at several field trials. This work includes a major U.S. open-air field trial in Nevada (2001), and a trial at DRDC Valcartier for a standoff distance of 5.7 km (Fig. 1B,C) [4,5]. Experiments such as these have clearly demonstrated the outstanding capability of the technique (CATSI and GASEM) for on-line monitoring and surveillance.

2. MoDDIFS SENSOR PROJECT

The success of the CATSI system for detecting chemical vapours has led to the development of a novel R&D prototype, MoDDIFS, to address the standoff detection of explosives and precursors [6]. The MoDDIFS system provides a differential imaging capability that may be useful for the passive standoff detection of vapours from particular explosives and precursors. This can provide early detection and warning of a belligerent's intent and their level of readiness to mount an attack with improvised explosives. The sensor is optimized for explosives and precursor detection based on phenomenological and modeling studies and a new library of relevant explosive and precursor signatures. MoDDIFS is a project sponsored by the Canadian CBRNE Research and Technology Initiative (CRTI) program.

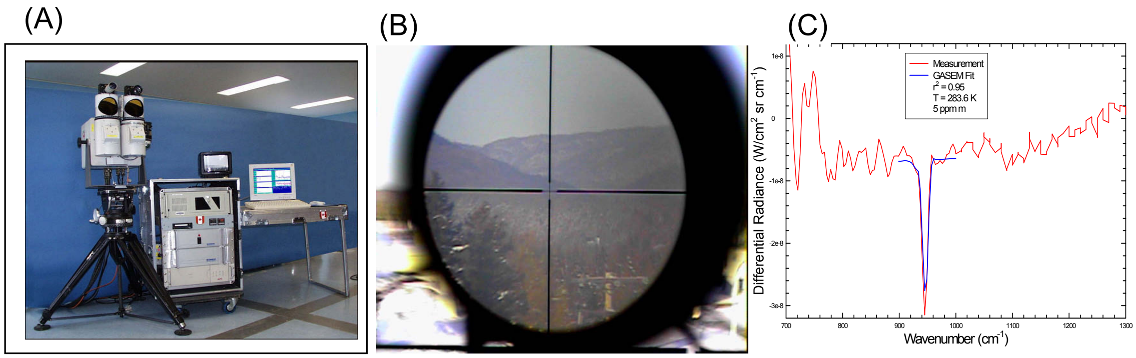

Figure 1: (A) Photograph of the CATSI instrument mounted on a tripod, (B) view of the 5.7-km long path facing towards the laboratory that contains the source, and (C) detection/identification of SF_6 at a distance of 5.7 km from the CATSI receiver.

Table 1 : Detectable Explosives and Precursors (non-exhaustive list)

Compounds	Material Class	Detectable Phase	Potential Detection	Detection Scenarios	Spectral Signature
TATP	Explosive	Vapor/Solid	YES*	Leak/Spill	YES
HMTD	Explosive	Vapor/Solid	MAYBE #	Leak/Spill	To be measured
RDX	Explosive	Solid	YES*	Spill	YES
PETN	Explosive	Solid	YES*	Spill	YES
Chlorates**	Explosive	Solid	MAYBE*	Spill	YES
Nitric acid	Precursor	Vapor/Liquid	YES*	Leak/Spill	YES
H2O2	Precursor	Vapor/Liquid	YES*	Leak/Spill	YES
Acetone	Precursor	Vapor	YES*	Leak/Spill	YES
Hexamine	Precursor	Powder	LIKELY*	Leak/Spill	YES

* If sufficient concentration; # If spectral signature exists; ** for e.g., potassium chlorate (other chlorates/perchlorates will be similar)

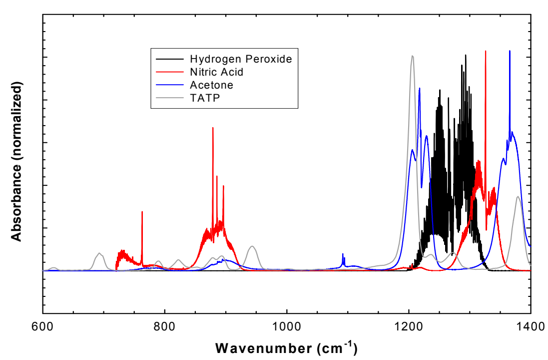

Figure 2: Absorbance spectra for vapours of important explosives and precursors.

3. LIST OF EXPLOSIVES AND PRECURSORS

Certain explosives and chemical precursors are more amenable to detection by a MoDDIFS-type sensor due to their relatively high vapour pressure and the presence of an IR signature. A preliminary list of relevant explosives and precursor chemicals and some sample signatures measured at DRDC Valcartier is presented in Table 1 and Fig. 2, respectively.

4. DETECTION OF EXPLOSIVE VAPOURS AND PRECURSORS

The methodology combines the clutter suppression efficiency of the differential detection approach with the high spatial resolution provided by the HSI approach. This consists of integrating an imaging capability of the advanced IR imager, Hyper-Cam (developed by Telops) with a differential CATSI-type sensor. A schematic presented in Fig. 3 summarizes the advantage gained by adding an imaging capability to CATSI, which forms the basis of the new MoDDIFS sensor. The CATSI sensor is optimized for probing spatially-large chemical clouds (cloud size of 10 m at a distance of 1 km). This limit determines the size of the detector, which is 1 mm in the case of CATSI. Therefore, the CATSI performance is limited when probing a plume that is smaller than the FOV of the sensor. A simple analysis based on signal-to-noise ratio (SNR) demonstrates the gain in sensitivity that can be achieved by adding a multi-pixel detector to a CATSI-like spectrometer. The SNR is an important parameter since it determines the sensitivity limit of a system. In general, spectral features of a target will be detected if they are at least three times as intense as the noise (i.e., SNR > 3). The SNR of a spectrometer having a single element detector is given by the following equation,

$$SNR = \frac{KD^2 A_{plume} B}{\sqrt{A_{\det}}}, \qquad (1)$$

where K represents the responsivity of the instrument, D is the diameter of the telescope, B is the number of photons/m^2 emitted by a plume that reaches the detector, A_{plume} is the area of the probed plume and A_{det} is the area of the detector. An important fact expressed by Eq. 1 is that the SNR is inversely proportional to the detector size (i.e., smaller detectors have higher SNR). Consequently, an FTIR imager that incorporates small pixel elements responds with higher SNR when probing small-dimension plumes [6]. This effect is summarized in Fig. 3(A,B), where the SNR of CATSI and MoDDIFS has been estimated for a typical explosive precursor scenario involving the detection of a 10-cm diameter plume of acetone at a distance of 300 m from the detector. For the CATSI sensor in Fig. 3A, the SNR estimate of 0.33 was obtained by scaling the SNR value of 10 determined from the measured spectrum of an acetone cloud in the laboratory, as shown in Fig. 3(C,D). By application of Eq. 1, the SNR corresponding to a 10-cm acetone cloud at a range of 300 m from the sensor is reduced to a value of 0.33 for a CATSI type-sensor with a 30-cm telescope and a 1 mm detector. The same scenario incorporating a MoDDIFS-type sensor with a detector size of 30 microns results in an estimated SNR of 10. This shows the advantage in SNR to be gained in using a MoDIFFS-type sensor to detect spatially-small vapour clouds at large distances.

5. DETECTION OF LIQUID AND SOLID EXPLOSIVE CONTAMINANTS

Polarization sensing with CATSI has also been tested with promising results for the standoff detection of liquid chemical warfare surface contaminants [7]. The proposed project will see this approach extended to the standoff detection of liquid explosives, precursors and powders [8]. Differential polarization measurements will substantially mitigate the spectral clutter arising in the measurement due to the natural variability associated with the background sky radiance. Fig. 4 shows a diagram in which the radiance from a VX-contaminated surface is probed by a sensor having either a polarizer oriented parallel (p-polarization) or perpendicular (s-polarization) to the plane of incidence. Subtracting the two polarized radiances yields the differential polarization radiance which is strongly perturbed by the presence of VX [7]. In a recent study it has been shown that even for thick contaminant layers, the differential polarization sensing approach is sensitive enough to detect and identify the refractive index signature of air-liquid interfaces. This attribute is promising for application to the standoff detection of liquid explosives and precursor spills. Although liquid explosives have been used only in rare occasions, the possibility of detecting explosive spills and precursors remains a valuable investigative tool.

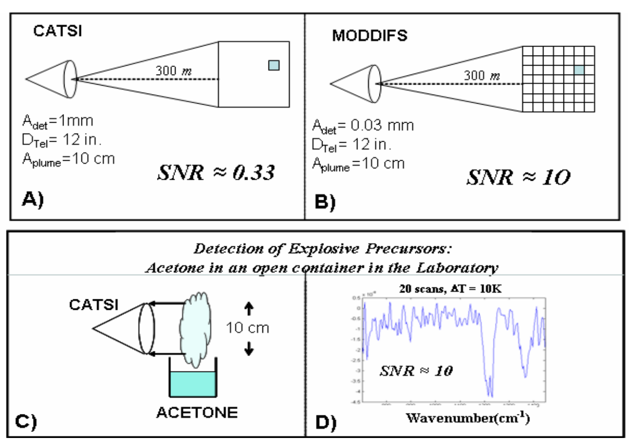

Figure 3: Evaluation of SNR for a MoDDIFS-type sensor based on SNR derived for CATSI.

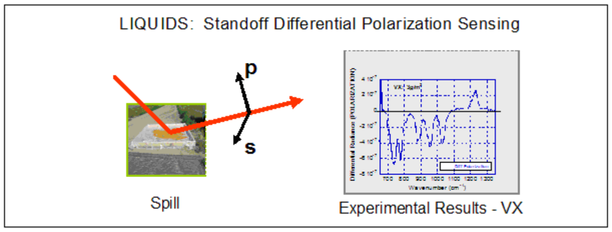

Figure 4: Differential polarization sensing scenario (left) and the resulting differential polarization spectrum showing the presence of VX.

6. CONCLUSIONS

Passive FTIR detection technologies have matured to a point where detector sensitivity, detection algorithms and phenomenology understanding appear now ready for application to the standoff detection of explosive materials. In particular, the unique differential sensing capability of the CATSI system has been well validated for chemical vapour detection at distances greater that 5 km. It is clear that this differential capability can be applied to the standoff detection of relevant explosives and their precursors. This can be realized through the development of a highly specialized differential imager, MoDIFFS, which will be optimized for the standoff detection of explosives and explosive precursors.

7. REFERENCES

1. J.-M. Thériault, *IR Fourier Spectrometer for Differential Detection: Design, Prototype and Results,* DREV R-9804 (1998).
2. J.-M. Thériault, *Modeling the responsivity and the Self-emission of a Double-beam Fourier-transform Infrared Interferometer,* Appl. Opt., 38, No. 3, pp. 505-515 (1999).
3. J.-M. Thériault, *Passive Standoff Detection of Chemical Vapors by Differential FTIR Radiometry,* DREV-TR-2000-156, 76 pages (2001).
4. J.-M. Thériault, E. Puckrin, F. Bouffard and B. Déry, *Passive Remote Monitoring of Chemical Vapors by Differential FTIR Radiometry: Results at 1.5 km*, Appl. Opt. **43**, 1425 (2004).
5. H. Lavoie, E. Puckrin, J.-M. Thériault and F. Bouffard, *Passive Standoff Detection of SF6 at a Distance of 5.7 km by Differential FTIR Radiometry*, Appl. Spectrosc., **59,** 1189 (2005).
6. J.-M. Thériault, E. Puckrin, H. Lavoie, F. Bouffard, S. Désilets, and P. Caron, *CRTI Project: Explosive Vapors Standoff Detector – Multi-Option Differential Detection and Imaging Fourier Spectrometer (MoDDIFS),* Public Security S&T Symposium 2009, Ottawa, Canada, June 16 (2009).
7. J.-M. Thériault, H. Lavoie, E. Puckrin, and F. Bouffard, *Passive standoff detection of surface contaminants: A novel approach by differential polarization FTIR spectroscopy*, Special Issue: IJHSES- International Journal of High Speed Electronics and Systems, **18**, 251 (2008).
8. E. Puckrin, J.-M. Theriault, H. Lavoie, D. Dubé and P. Brousseau, *Novel application of passive standoff radiometry for measurement of explosives*, Special Issue: IJHSES- International Journal of High Speed Electronics and Systems, **18**, 307 (2008).