Simplified and Low Cost Optical Remote Sensing Technology for Fenceline Monitoring of Fugitive Releases

Extended Abstract 2010-A-190-AWMA

William A. Mitchell and Eben D. Thoma
Office of Research and Development, National Risk Management Research Laboratory, U.S. EPA, 109 TW Alexander Drive, E343-02, RTP, NC 27711, USA
Cary Secrest
Office of Civil Enforcement, U.S. EPA, Ariel Rios Building Rm 2119, 1200 Pennsylvania Ave., N. W., Washington, D.C. 20004, USA

INTRODUCTION

Reducing fugitive emissions of hazardous air pollutants from industrial facilities is an ongoing priority for the U.S. Environmental Protection Agency (EPA). Unlike stack emissions, fugitive releases are difficult to detect due to their spatial extent and inherent temporal variability. Fenceline monitoring using optical remote sensing (ORS) can significantly augment existing leak detection and repair programs by helping workers quickly pinpoint and repair fugitive leaks, greatly decreasing the potential for emissions. However, such monitoring is rarely conducted voluntarily, largely due to the cost and complexity of existing ORS instruments. For these reasons, there is a priority need for an ORS technology that meets the cost and performance criteria necessary for broader acceptance of ORS approaches by industry and EPA's regulatory programs. An example of a multipath scanning ORS fenceline monitoring system providing complete fenceline coverage is shown Figure 1.

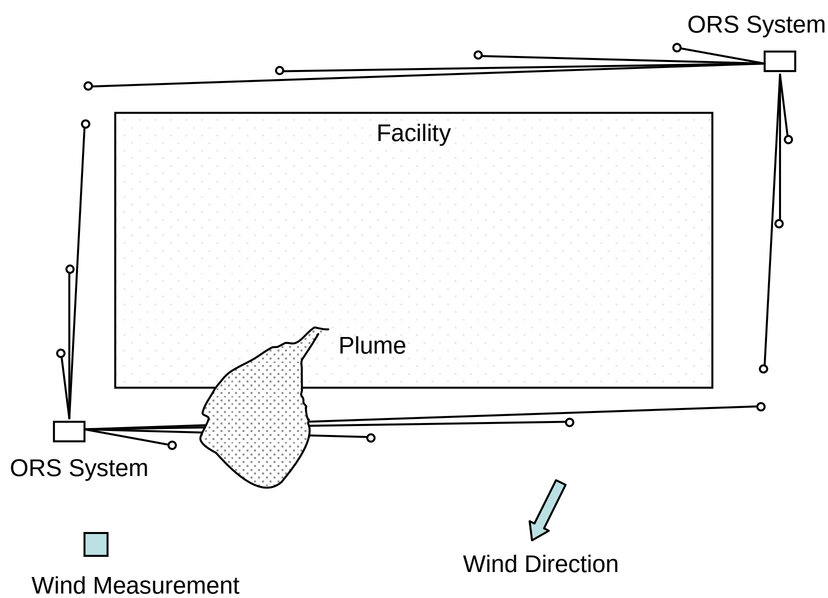

Figure 1: Envisioned of multipath ORS fenceline monitoring system.

For this example, the entire perimeter of the facility is covered by two ORS systems which sequentially scan over multiple beam paths. The system configuration can be bistatic (separate source and receivers) or monostatic (combined source and receiver using retro reflecting mirrors). The envisioned system would provide real time data, scanning the entire facility within seconds. The data would be linked to a meteorological station acquiring real-time wind data. Custom software included in the package would allow for rapid localization of events (leaks) within the facility.

A critical component of the envisioned fenceline system is a simplified ORS technology that would allow cost-effective implementation of the concept. The system would be capable of robust unattended operation, long optical path lengths (1 km), high sensitivity, and the ability to detect multiple compounds simultaneously. Ideally the operational and capital costs of the system would be significantly lower than currently available commercial systems for complete fenceline coverage applications. The ability to provide speciated measurements is seen as a secondary priority for this application compared to the other desired design characteristics. If speciated measurement is desired, the fenceline system could be used to rapidly trigger selected canister sampling (or other measurement) in the plume area to establish compound identification at a later date. The omission of speciation capability for this type of "detector" system is believed to simultaneously reduce instrument cost, increase operational robustness, and broaden its application.

To further investigate the utility of this concept, EPA is developing a simplified and low-cost ORS approach for robust fence line monitoring. The ORS system, called the deep ultraviolet optical sensor (DUVOS), utilizes discrete regions in the deep ultraviolet spectrum that allow for highly sensitive, non-speciated gas detection with greatly simplified analysis and optical design requirements. This approach simultaneously reduces the cost of the sensor platform, decreases its complexity, and increases its operational robustness and detection performance. The poster presentation will focus on technical design elements of the DUVOS technology and will present results of performance testing of the first prototype.

DUVOS SYSTEM DESIGN

The EPA has utilized commercial available and customized ultraviolet (UV) and Infrared (IR) ORS equipment for spatially-resolved characterization of sources.[1-4] Existing commercial ORS systems can produce speciated measurements and can be deployed successfully for fenceline monitoring applications. The current EPA research effort seeks to develop both UV and IR ORS systems with improved cost and performance factors compared to commercially available systems. The prototype UV system, DUVOS described here is a custom-designed open-path bistatic instrument. The principle of operation is differential absorption of light in the 200 nm range compared to the 280 nm range. Numerous inorganic and organic hazardous air pollutants, excluding saturated hydrocarbons, possess strong broadband absorption in the 200 nm spectral region due to pi to pi* absorption. The broad features terminate in the 210 nm to 230 nm region depending on the compound and are very difficult to speciate due to lack of fine structure with the exception a few compounds. The DUVOS system is based on balanced differential comparison of light throughput in the two spectral regions using a broadband detection scheme employing bandpass filters and solar dual channel detection obviating the need for a spectrometer, which greatly reduces the cost and complexity of the approach.

The chassis and optical assemblies for the DUVOS prototype are 15.24 cm dia. Cassegrain format and were supplied by Industrial Monitor and Control Corporation (Round Rock, TX). The current prototype unit utilizes a deep UV deuterium lamp although other sources are being investigated. Special optical coatings are utilized for superior performance in the 200 nm to 300 nm spectral range. Design, component selection, final fabrication, and testing were completed at the EPA ORD research facility in Research Triangle Park, North Carolina. Priority design considerations were given to total unit cost, robustness, and serviceability.

Operationally, the source modulated and collimated ultraviolet beam is received by a telescopic detector assembly (Figures 2 & 3). The detector assembly includes a beam splitter to separate the incoming light into one filtered signal channel and one filtered reference channel. The signal channel filter is chosen for a spectral bandpass frequency that is absorbed by the compound(s) of interest. The reference filter is chosen for a spectral bandpass frequency where the compound(s) of interest is not absorbed and little interference exists. The detectors are solar blind photomultiplier tubes (PMTs) chosen for high gain in the 200 nm to 300 nm frequency range, simplistic electrical interface, and robustness. The two detector channels are then fed into a data acquisition system running two lock-in amplifier algorithms. Lock-in amplification is used to reject non-modulated background light. Both the signal and reference channels lock-in to the same modulated reference frequency. The ratio of the two lock-in amplifier outputs is then calculated. Time of day, signal channel lock-in voltage, reference channel lock-in voltage, ratio, and reference frequency are periodically recorded by a computer.

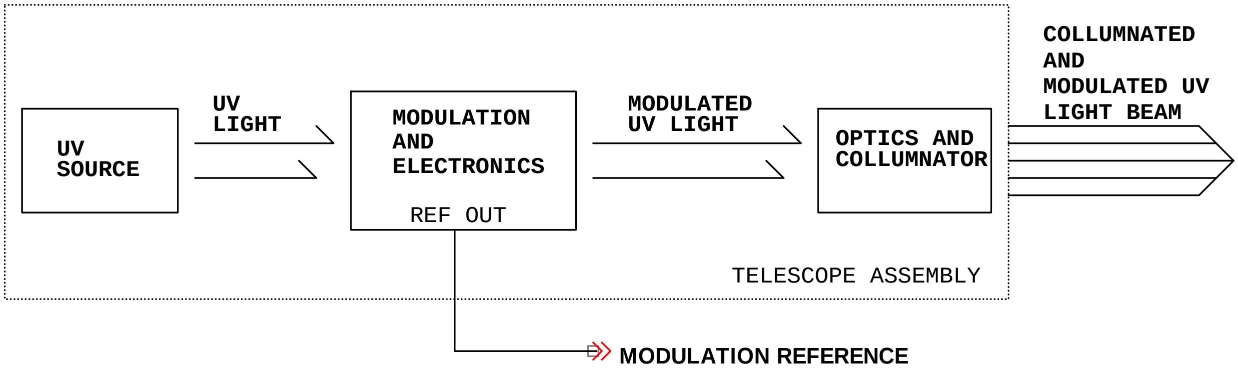

Figure 2: The DUVOS source assembly

For calibration and in-field quality assurance purposes, two 20 cm diameter cylindrical optical cells were utilized. One cell, 0.2606 m long, is used for indoor testing and the other, 1 m long, is used for outdoor range testing. The optical cells are designed to be easily inserted into the beam path without significant optical loss. The stainless steel optical cells are fitted with 20 cm diameter 0.32 cm thick S1 grade quartz windows. The windows are secured with steel rings and PTFE gaskets. The optical cells have standard gas line fittings to allow for flow-through operation of calibration and test gases.

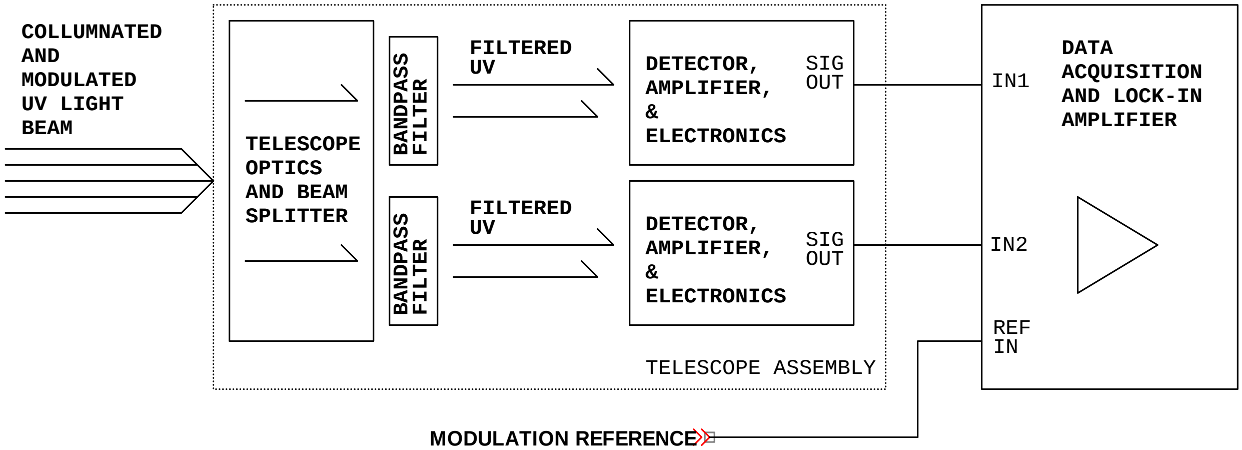

Figure 3: The DUVOS receiver assembly

Results and Discussion

To date several instrument performances scoping tests have been conducted. These include evaluation of instrument function and control software, basic instrument response to a four-component mixture, and range testing. Preliminary laboratory results are discussed below with additional 200 m range results to be included in the poster presentation.

Figure 4 shows the preliminary instrument response to a hydrocarbon mix in laboratory conditions. Absorbance peaks are calculated in parts per million meter (ppmm). These data were produced using the 0.2606 meter optical cell with a 108 ppm gas mix of approximately equal amounts of benzene, ethyl benzene, o-xylene, and toluene with a balance of nitrogen. The reference was further N_2 diluted using a calibrated Environics Series 2000 multi-component gas mixer in flow-through mode. From the graph below, it can be seen that detection limits of well below 1.0 ppmm are possible, especially with currently available pmt gain, additional noise filtering and signal averaging.

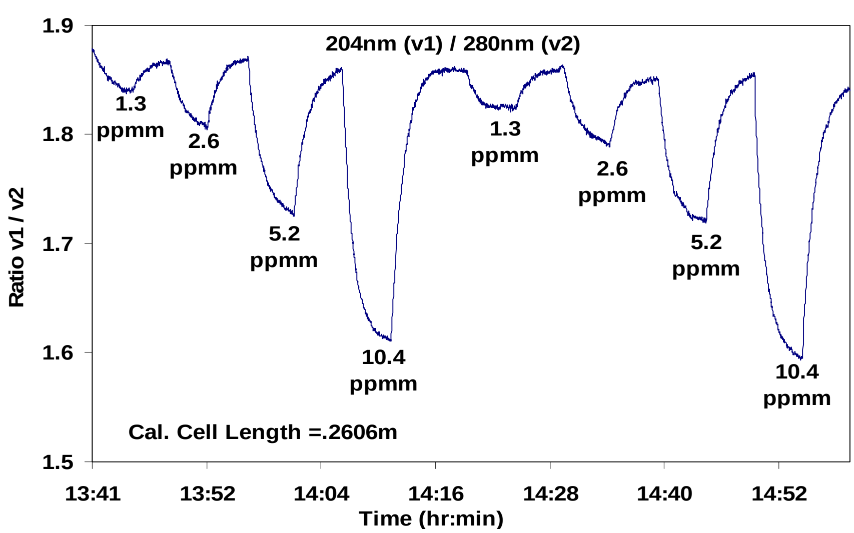

Figure 4: Instrument response to hydrocarbon mix in the laboratory.

Figure 5 shows instrument absorbance linearity from two data sets. The offset seen between the two data sets can be attributed to zero drift. This will be compensated for with the addition of automatic gain control circuitry and software.

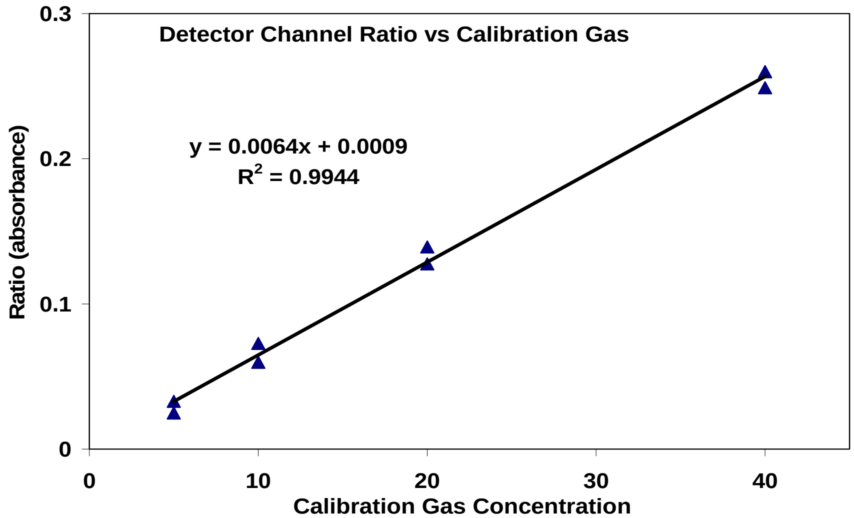

Figure 5: Instrument response curve for in-lab testing.

SUMMARY

This extended abstract reports on preliminary scoping studies of instrument performance of a prototype DUVOS open-path non-speciating spectrometer in the context of fenceline measurements. The preliminary studies have shown that the DUVOS instrument has sufficient sensitivity and path length capability to be useful for envisioned future EPA fenceline monitoring. While this abstract reports on initial data, it is hopeful that additional EPA quality assured results will be available for presentation at the conference.

REFERENCES

1. Thoma, E. D.; Thompson, E. L.; Shores, R. C.; Harris, D. B. Measurement of Low Level Air Toxics with Modified UV DOAS, Paper #270, 99th Annual Conference of the Air & Waste Management Association, New Orleans LA, June 20-23, 2006.
2. Thoma, E.D.; Shores, R.C.; Isakov; V. Baldauf, R.W., Characterization of Near Road Pollutant Gradients Using Path-Integrated Optical Remote Sensing, J. Air & Waste Manage Assoc. **2008,** *58*, 879-888.
3. Thoma, E. D.; Secrest, C.; Hall E. S.; Jones, D. L.; Shores, R. C.; Modrak, M. T.; Hashmonay, R.A.; Norwood, P.; Measurement of Total Site Mercury Emissions From a Chlor-alkali Plant Using Ultraviolet Differential Optical Absorption Spectroscopy and Cell Room Roof-vent Monitoring, Atmos. Environ. **2009,** *43*, 753-757.
4. Thoma, E. D.; Shores, R. C.; Thompson, E. L.; Harris, D. B.; Thorneloe, S. A.; Varma, R. M.; Hashmonay, R. A.; Modrak, M. T.; Natschke, D. F.; Gamble, H.A. Open Path Tunable Diode Laser Absorption Spectroscopy for Acquisition of Fugitive Emission Flux Data; J. Air and Waste Manage. Assoc. **2005**, *55*, 658-668.

DISCLAIMER

This article has been reviewed by the Office of Research & Development, U.S. EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use.