Investigation of a Low Cost Sensor-Based Leak Detection System for Fence Line Applications

Extended Abstract: #26

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INTRODUCTION

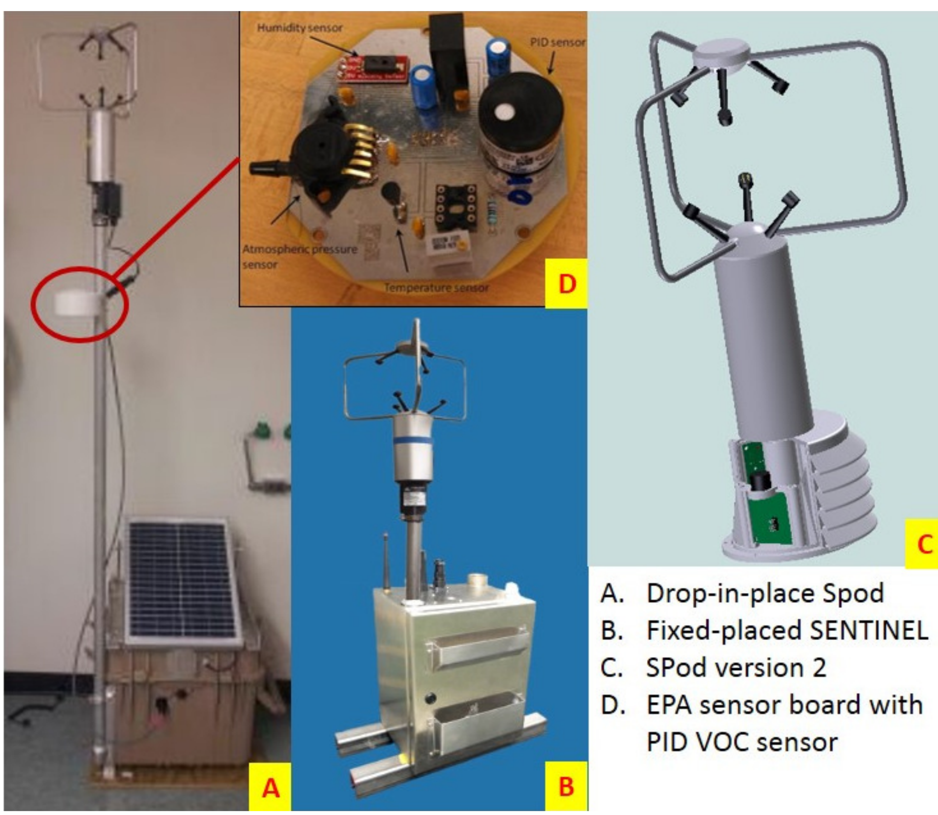
As part of the Petroleum Refinery Risk and Technology Review, New Source Performance Standards rule,[1] the U.S. Environmental Protection Agency (EPA) has proposed a passive sorbent tube fence line monitoring approach for benzene. Time-integrated passive sampling can establish average concentrations around a facility and point to potential problem areas, but the information provided is not real-time and reflects integrated source contributions in the area.[2] Time-resolved measurements that combine pollutant concentration and wind data can be used to support passive sampling strategies by helping to decipher the origin of emissions and provide time-stamped information on fence line concentrations. Reflecting a wide spectrum of performance and implementation costs, time-resolved fence line measurement approaches range from powerful open-path spectroscopic systems and field-deployed gas chromatography to lower costs for "leak detection" systems. This project explores the very low end of the cost and performance curve through investigation of a prototype sensor-based leak detection system for fence line applications developed by EPA's Office of Research and Development (ORD). This project is part of a larger ORD effort called SEnsor NeTwork INtelligent Emission Locator (SENTINEL) that combines time-resolved measurements and inverse models of various forms to improve source understanding on a variety of spatial scales.

This fence line sensor exploratory project is part of a larger collaboration with EPA Region 3, and the City of Philadelphia, Department of Public Health Air Management Services that started in the summer of 2013.[3] The overall effort investigates how passive samplers in combination with real-time measurements can help improve information on air pollutant concentrations in complex air sheds. The prototype system described here was developed and deployed near a refinery in South Philadelphia in July, 2014, with operation continuing into 2015. The objective of this project is to improve understanding of the performance and robustness of this class of low-cost sensor-based system and to evaluate the potential for these systems to provide useful information in fence line applications. Basic information regarding the siting of the prototypes and the concept of emision detection and source triangulation is presented elsewhere.[3] This extended abstract describes the prototype design, basic performance, and introduces data analysis concepts with further information on field results available for presentation at the conference.

EXPERIMENTAL METHODS

The prototype described here is categorized as a stand-alone air measurement (SAM) system. A SAM combines low-cost air quality sensors, and/or higher performance instruments with other hardware to produce a measurement approach that can be field-deployed without significant supporting site infrastructure (such as an air quality monitoring trailer). The current prototype network consists of a solar-powered "sensor pod" (SPod) and line-powered SENTINEL base station.[3] The SPod is controlled by a low cost and low power consumption Arduino UNO computer and communicates with the base station using a short range ZigBee® (IEEE 802.15.4) network. The base station contains an Intel Atom™ computer (Santa Clara, CA, USA) running a custom LabView™ (National Instruments, Austin, TX, USA) data acquisition program and communicates to the outside world using a cell phone modem. Both the SPod and the SENTINEL base station are capable of supporting wind measurements but for this deployment only the latter is fitted with a model 81000V 3-D Ultrasonic Anemometer (R.M. Young, Inc., Traverse City, MI, USA). Both systems log time-synchronized data at 1Hz and use a custom EPA-developed sensor board containing the following sensors: 10.6 eV passive photoionization detector [PID] (white or blue label piD-TECH®, Baseline-Mocon Inc. Lyons, CO, USA); relative humidity (HIH-4030 Honeywell, Morristown, NJ, USA); atmospheric pressure (MPX4115AP, Freescale Semiconductor, Tempe, AZ, USA); and atmospheric temperature (MCP9700A, Microchip Technology, Chandler, AZ, USA). Components for the systems are shown in Figure 1 with site photos in a companion paper.[3] Figure 1C shows a second generation integrated SPod design that will begin testing in 2015.

Figure 1. EPA Prototype System Components.



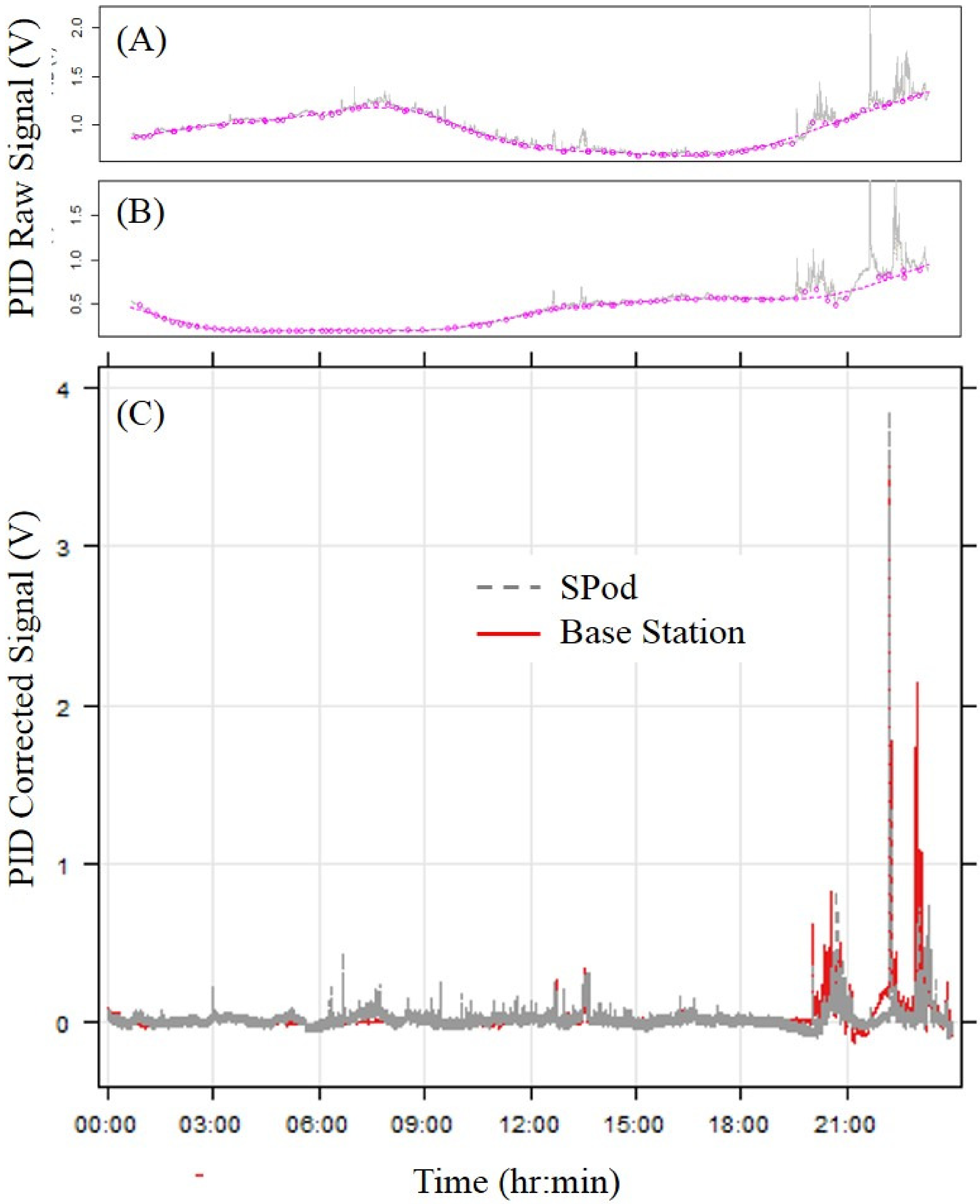
The primary objective of this project is to explore the use of uncontrolled low cost PID sensors to detect volatile organic compounds (VOCs) in a continuous fence line deployment with minimal operator intervention. It is well known that PID sensor response and calibration baseline stability are affected by temperature, humidity, static charging, lamp deposition and other variables.[4,5] There are several commercially available PID-based hand-held systems that can achieve ppb level concentration measurements. These systems employ pumps to deliver the samples to the PID and a variety of engineering controls, operation procedures, and data processing algorithms to correct environmental effects and to stabilize the operation of the system. Since the hand-held systems are used "on demand", daily calibration checks and baseline zeroing procedure are part of standard operation and can result in well-controlled performance. As an extension of hand-held packages, commercial PID-based systems for continuous fence line monitoring application at the ppb level may become more widely available in the future. These systems would likely also employ engineering design controls such as inlet air conditioning and instrument temperature stabilization (heating) and procedural controls such as daily zeroing to improve data quality. These features and procedures, however, can increase implementation and operation costs (e.g., increased instrument cost, need for power drops, daily adjustment). The current project investigates a lower cost alternative that has a passive (no pump) PID with no secondary controls or conditioning. In the current design, no attempt is made to actively stabilize the baseline drift of the sensor or perform daily adjustments. Instead, the raw signal from the PID is analyzed in an attempt to decouple the source signal from baseline drift, potential artifacts and air shed effects. In the context of the developing spectrum of time-resolved fence line measurement options, the current approach is at the low end of the cost and performance curve producing an uncalibrated VOC response signal that, when coupled with wind information, can help inform the origin source of emissions and facilitate determination of speciated concentrations through triggered acquisition of evacuated canister samples.

For this application, the operable assumption is that the PID response (signal) is comprised of two primary components which differ in temporal character. When observed from a fixed single point location, the wind-advected plume from a proximate emission source produces a rapidly changing time-dependent concentration profile (measured in seconds) that we call here the source signal. This effect has been studied using high-fidelity instrumentation in other EPA programs.[6,7] The other primary signal is by comparison, slowly varying in time (measured in minutes to hours), and consists of a combination of baseline drift in the PID sensor and actual changes in background pollutant concentration in the air shed that are measured by the PID.

In order to better understand the presence of a near-field source signal, we looked for periods of similar response on the SPod and SENTINEL units (physical separation 50 m).[3] A source signal emanating from the facility to the west should be registered by both systems whereas a slowly varying non-target signal may differ between the two systems. Figure 2 shows an example of time-resolved raw PID signal on one measurement day for (A) the SPod and (B) the SENTINEL base station. The signal on both units is characterized by low and high frequency components with the former outlined by the purple traces, calculated using a modified version of a spline of minimums method developed by Brantley et al.[8] Once the baseline is defined, it can be separated from the assumed source signal producing the baseline-corrected traces in Figure 2 (C). The current version of the baseline correction algorithm performs well in most cases, but further optimization is being explored. Presently, an amplification gain of 40x is used on the PID signal.

Using this gain, the PID signal can drift off scale resulting in lost data. The occurrence of off-scale readings was reduced by changing the sensors from "White" to the more stable "Blue label models" but the gain of 40x likely needs to be reduced in the next generation of units, somewhat reducing detection sensitivity. These factors will be further discussed in the presentation.

Figure 2. Example of Baseline.



RESULTS

A survey of data from the first six months of deployment shows that many of the sampling days contained off-scale readings on one or both units and/or did not show a strong high frequency signal (assumed source signal). To explore analysis options, a total of 28 days were selected that exhibited both on-scale measurements for the entire day and source signal response on both units. General findings on data completeness and the results for the selected data set will be discussed in presentation along with some preliminary data analysis concepts.

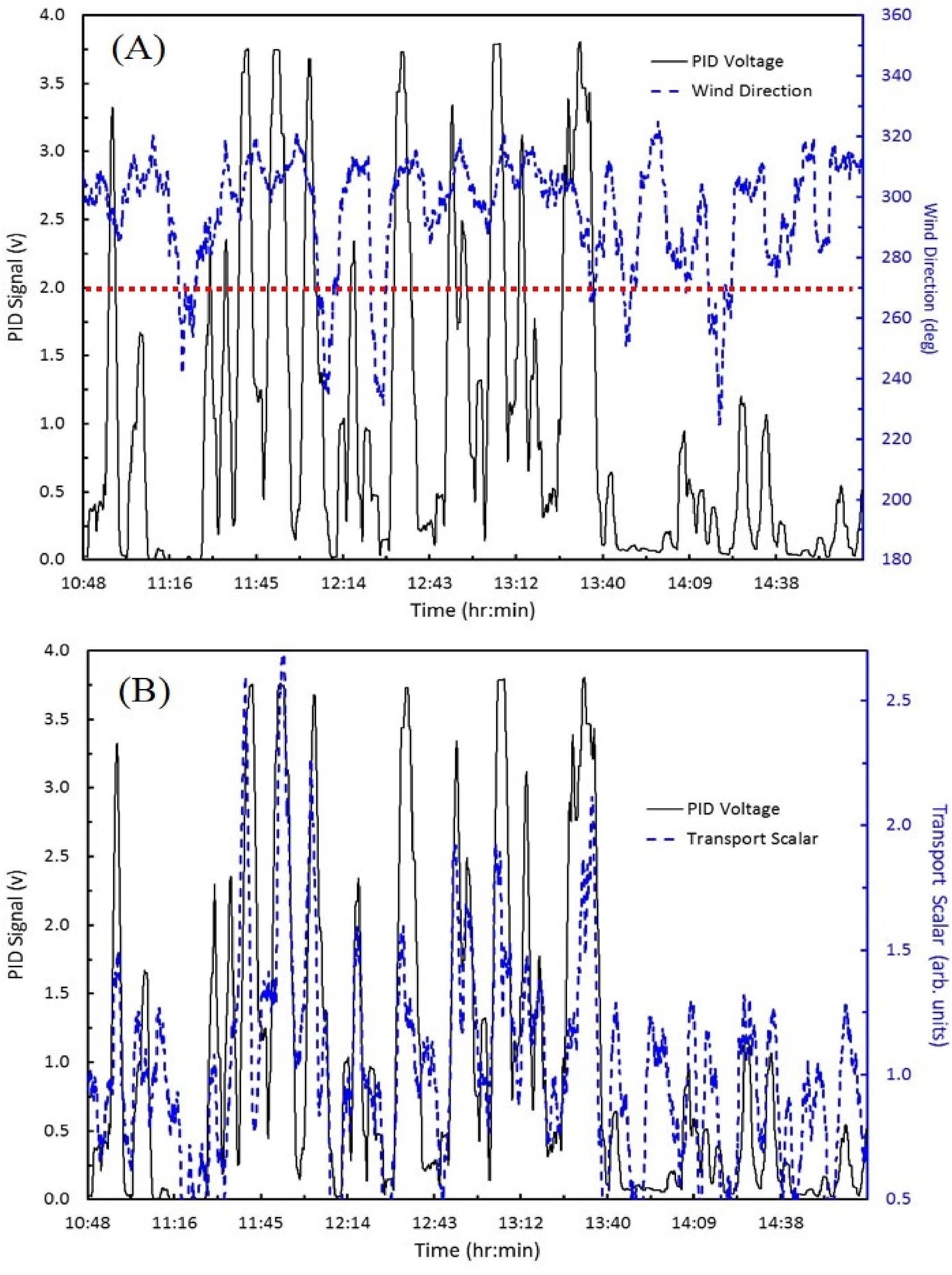
One such analysis approach is shown in Figure 3. Similar to the example of Figure 2, for this day, no source signal was evident until mid-morning and then a high frequency signal from an assumed near-field source appeared simultaneously on both the SPod and SENTINEL systems. One way to explore the angular position of a potential upwind source is to assume a direction required for plume transport from the source area to the measurement location (and define a unit vector) and then investigate the time-resolved projection of the measured wind vector onto this transport direction. Figure 3 shows baseline-corrected SPod data (primary ordinates) compared with wind direction and a transport scalar [secondary ordinates, 3(A) 3(B), respectively]. For this example, the source location is assumed to be due west, from 270 degrees (red-dashed line in Figure 3(A). The transport scalar is formed by a dot product of the easterly unit the instantaneous wind vectors. Here a five-minute moving average of the native 1 Hz data is used for ease of viewing. The wind speed for this time period was 2.31 m/s (σ = 0.35 m/s). Using only the wind direction, some understanding of signal variation and consequently upwind source location can be inferred. The transport function, however not only includes direction but also wind speed information which will influence plume transport to the measurement location (e.g., as wind speed approaches zero, transport approaches zero). In Figure 3 (B) for example, there a general decrease in both signal and the transport scaler for times past 13:40 which is not as evident in Figure 3(A). The transport scaler is also more convenient for numerical comparison to the recorded PID signal. This simple transport function can be augmented with atmospheric stability information (influences of plume rise and effective upwind fetch) and other scaling factors. The transport unit vector can in principle be selected through an iterative optimization scheme and potentially allow for multiple sources in the upwind direction to be identified. The use of time-synchronized data from multiple sufficiently separated units can also be a source diagnostic.

SUMMARY

This abstract reviews progress in exploring a simple PID sensor-based leak detection system that represents the low end of the cost and performance curve for time-resolved fence line monitoring applications. The SPod and SENTINEL base station systems developed by EPA ORD are described and initial analysis approaches are discussed. In this study, we learned about deployment robustness and sensor response factors of an uncontrolled PID system in real-world deployment setting. The system is judged to be potentially useful for fenceline diagnostics although much work is required to further drift compensation and leak detection calculation approaches. Further information on the results of the prototype deployment in South

Philadelphia, data analysis concepts, and progress to develop the revised version of the system will be presented at the conference.

Figure 3. Potential Analysis Approach.



ACKNOWLEDGEMENTS

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KEY WORDS

Fence line, volatile organic compounds (VOCs), sensor, field measurements