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SUMMARY/CONCLUSIONS

We integrated backscatter laser technology with a small Unmanned Aerial Vehicle to create a new platform for natural gas leak survey and quantification. Simulated flights with the sensor system deployed on a rotating 10m diameter boom successfully located and quantified emission rates from a known methane source. Actual low-altitude flights conducting raster pattern surveys of wellhead infrastructure located, visualized, and estimated flux from leaks smaller than 5 scfh.

BACKGROUND

Methane is a potent greenhouse gas (GHG) when vented to the atmosphere and methane emissions from natural gas expansion could undermine the benefits of using lower carbon natural gas for power generation. Current monitoring methods are limited due to cost and difficulty in locating and quantifying the rate of the methane emissions.

Leak detection practices include scheduled periodic walking, driving, or aerial surveys. Thousands of leak detection tools and devices are currently deployed worldwide to protect against potentially explosive leaks. Because there is no convenient technology for measuring leak rate, the current leak survey rules and practices make no provision for prioritizing repairs based on emission rate. This paper describes the use of active backscatter laser technology deployed on a small Unmanned Aerial Vehicle (sUAV) to survey, locate, and quantify leaks at upstream sites such as wellpads.

Active backscatter lasers sensors in current service provide remote or standoff leak detection, meaning the detector need not be inserted into the emission plume to detect the emission.[1] They transmit infrared beams through emission plumes and capitalize on optical spectroscopy to detect target gases that absorb the infrared light. In current practice, they locate leak sources by manual or mobile scanning, and provide quantitative measurements of path-integrated concentration. Figure 1 illustrates the principles: an eye-safe infrared laser beam emanating from a transceiver illuminates a remote natural surface and the transceiver detects laser light scattered or reflected from the illuminated surface. The laser beam carries a signal that is analyzed to accurately deduce the amount of methane in the path the beam traverses, independent of background characteristics, ambient light, other ambient gases or environmental effects. In routine use, the handheld device detects emissions smaller than 2 SCFH. To detect leaks, the operator manually scans the laser beam across the area of interest, be it the surface above an underground pipeline or the region around a gas meter or pipe fitting. The laser continually measures the path-integrated methane concentration (in units of ppm-m) along the line traversed by the laser beam between the operator and the surface illuminated by the laser. If, during the scan, the laser detects a marked change in methane concentration indicative of the beam passing through a leak plume, the instrument activates an alarm.

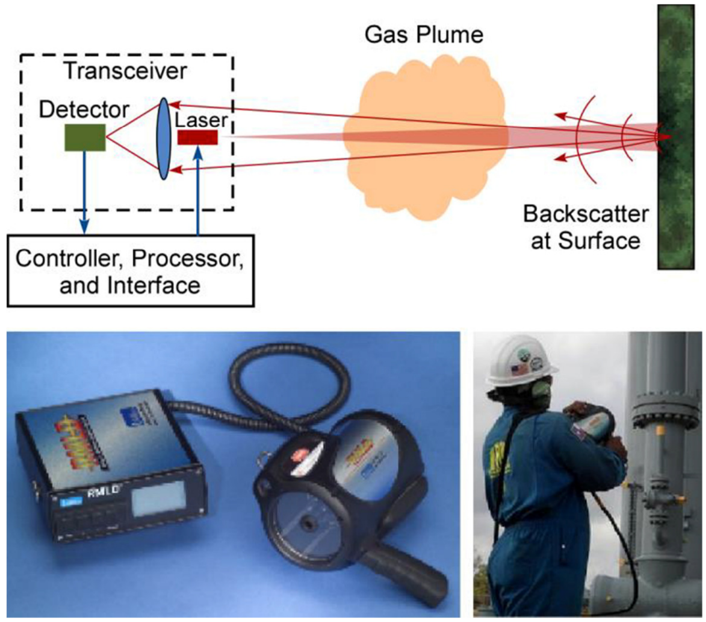

Figure 1. Backscatter Tunable Diode Laser Absorption Spectroscopy and illustration of use in natural gas leak surveying.

AIMS

In an effort to provide an affordable sensing system which would enable more effective methane mitigation programs, Physical Sciences Inc. (PSI) and Heath Consultants Incorporated (Heath) adapted the remote methane leak detection (RMLD) laser-based technology for mounting on PSI's two-foot-wide quadrotor Unmanned Aerial Vehicle (UAV) featuring highly advanced autonomy and all-weather operation. Using this RMLD-UAV platform, we are developing a system for continuous leak monitoring with automated leak localization and quantification, intended for widespread cost-effective deployment at wellheads and other gas infrastructure sites.[2]

METHODS

For aerial leak survey and quantification, we developed a smaller version of the laser sensor and adapted it to the high-performance all-weather sUAV depicted in Figure 2 and described by Table 1. This technology projects the laser beam towards the ground below and receives light backscattered from the ground surface. It measures the column-integrated methane between the vehicle and the ground. By flying self-directed patterns around a methane leak and using a mass-balance calculation [3], we deduce the leak rate and centralize on the leak location.

Figure 2. Backscatter Laser Sensor and Small UAV system the RMLD-UAV.

Table 1. UAV Vehicle Characteristics

Purpose	Natural Gas Leak Survey and Quantification
Technology	Methane detection via backscatter-laser spectrometer on small quadrotor UAS w/video
Size	24” diameter, 9” depth
Weight	Approximately 3 lb with battery
Flight Range	Within visual sight (<2000 ft) of base station
Survey Altitude	30 ft. typical
Endurance	30 min
Wind	30 mph
Control	Handheld GCS Optional laptop computer for semi-autonomous flight w/real-time waypoint updating Automated vertical launch and land
Lost Recovery	GCS locates after remote landing
Methane and GPS Data	Class 1 Bluetooth
Video Data	680 x 480**,** 5.8 GHZ analog transmission
UAS Storage	System stows in 18” x 24” x 10” case

RESULTS

Figure 3 presents the results of early tests that deployed the laser sensor on a rotating 10m diameter boom rotating at 5 rpm to emulate a possible flight pattern of the UAV system. We scanned laser curtains, illustrated by Figure 4, around a 13 scfh leak source at several radii. Notably, the plume lies outside of the inner cylinder, and the flux computed for that cylinder is nearly zero, as expected.

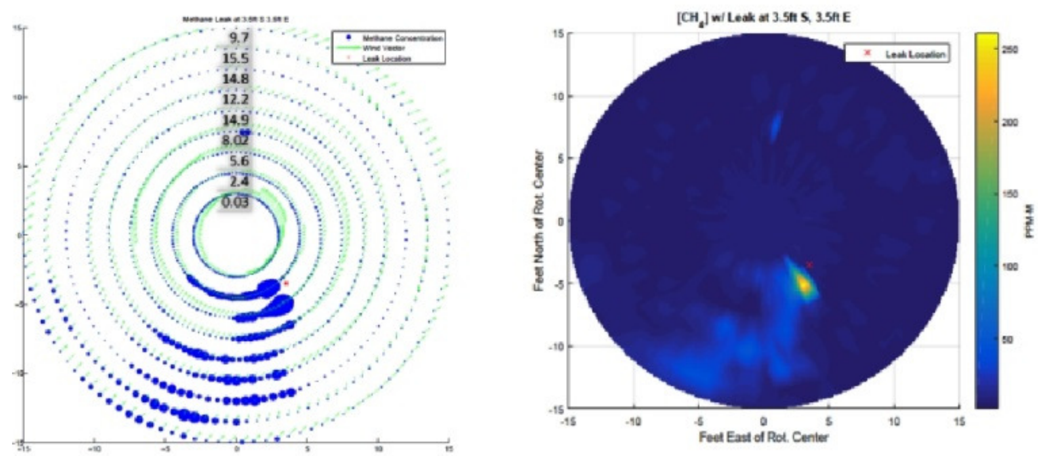

Figure 3. a) Circular scans around a 13 scfh methane source located at the red dot. Each circle depicts the methane column-integrated concentration vs position, with associated wind vectors measured at the time of each measurement, averaged over 10 rotations acquired in 2 minutes. The numerical value associated with each circle is the computed flux. The average flux for all circles (excluding the inner which the plume does not intercept) is 11.6 scfh. b) The same data presented as a colorized image enabling visualization of leak origin.

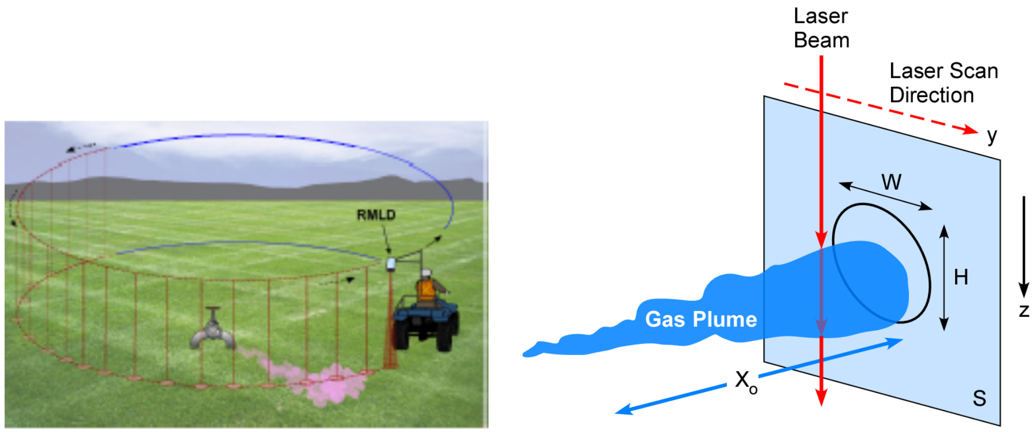

Figure 4. (left) Notional illustration of a “laser curtain” scanning a perimeter surrounding a leak source. (right) Flux calculation schematic. The linear laser beam measures column concentration integrated along z-direction and temporally scans the S-plane in the y-direction. Flux is deduced by integrating over position and multiplying by the wind vector.

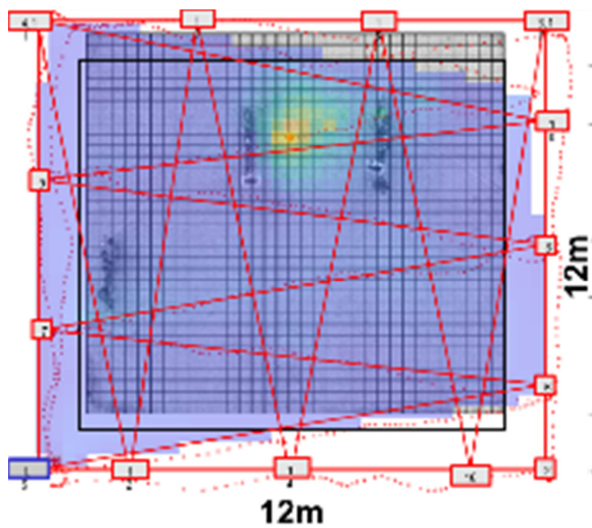

Figure 5. Example RMD-UAV flight pattern surveying a wellpad, and data visualization product.

We flew the RMLD-UAV at a height of about 10 m above a simulated experimental gas wellpad depicted in Figure 5. A natural gas flow of known rate was created manually on a piece of the infrastructure. To locate and characterize this leak, the RMLD-UAV executed a raster-pattern search, nominally illustrated by the red lines in Fig.5, measuring column-integrated methane concentration along the raster pattern at nominally two points per meter. After completing the survey and recording the downloaded data, software interpolates between measurement points to create a pixel grid (the blue lines of Fig.5). Each pixel is colorized in accordance with the interpolated concentration. The resulting 2D data reconstruction provides quantitative images of path-integrated methane concentration depicting methane plumes. The plume images are overlaid on visible camera imagery. From these quantified plume images, emission rate is deduced using a mass-balance approach: Pixels forming a perimeter encompassing the leak source are selected for analysis. Emission flux is calculated as the integral over the perimeter of the vector product of the TDLAS data (ppm-m) and the local wind velocity vector (m/s). Wind was measured by a local portable anemometer. In the example of Fig.5, the RMLD-UAV system estimated the leak rate to be 31 scfh; the metered actual rate was 23 scfh.

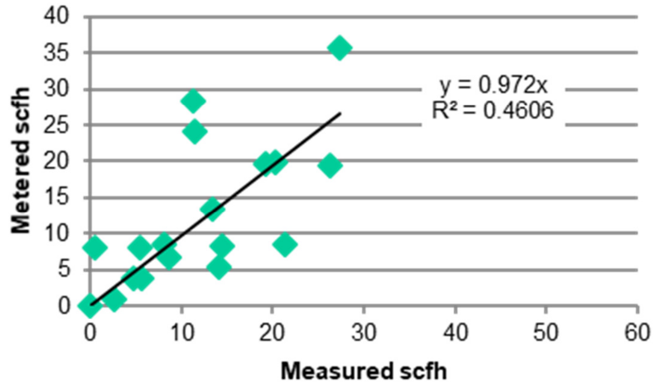

Figure 6. Comparison of emission rate deduced by the RMLD-UAV system vs the actual metered leak rates for 18 distinct scenarios.

Figure 6 plots the RMLD-UAV estimated leak rate vs. metered flow rate for 18 similar flight scenarios with leak rates ranging from 0 to 30 scfh. The RMLD-UAV system deduced the flow rate within 20% accuracy for 28% of tests, within 50% accuracy 50% for 56% of tests, and within 70% accuracy for 83% of tests.

REFERENCES

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[2] Frish, M.B., RMLD Sentry for Upstream Natural Gas Monitoring", Presentation to ARPAe Energy Innovation Summit, National Harbor, MD, PSI-VG-2016-017, March 2016

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